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投稿規定

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2 論文及び報文（以下「論文等」という。）の内容

未発表の原稿で、海洋（物理・化学・生物・地質など）及び海上気象（波浪・海氷・海気相互関係など）に関する論文並びに気象庁における海洋・海上気象業務の活動、そのために開発された測器及び方法に関する報文など。

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- (1) 用語は、欧文（原則として英文）とする。
- (2) 論文等には、英文（300語以内）及び和文（800字以内）の要約を付ける。要約は、方法・測器・実験・観測の結果・仮定・理論などの中味が読みとれるように留意し、なるべく指定の長さで簡潔に書く。
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ALLEN, W.E. (1927): Surface catches of marine diatoms and dinoflagellates made by U.S.A. Pioneer in Alaskan waters in 1923.

Bull. Scripps Inst. Oceanogr., Tech. Ser. 1(4), 39-48.

BUDYKO, M. I. (1956): *The heat balance of the earth's surface*. Hydrometeorological Publishing House, Leningrad, pp. 254.

VERONINS, G. and H. STOMMEL (1956): The action of a variable wind stress on a stratified ocean. *J. Mar. Res.*, 15(1), 43-75.

4 提出方法

投稿票を付け、本稿のほかにコピー（図及び表を含む。）2部を添える。

5 送付先

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6 その他

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Effect of the zero-drift in ocean wave records on the wave statistics by the zero-up-crossing method

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(Received October 19, 1983; Accepted January 20, 1984)

Abstract: An error in the average quantities of the zero-up-crossing waves when a stationary drift of the mean level appears in the wave records is examined based on a statistical theory on wave heights. The measured wave height and period are found to increase apparently with the drift of the mean level. The theoretical relations of the measured values to the drift are applied to the ocean waves observed by the JMA Ocean Data Buoy No. 6 in the Japan Sea.

1. Introduction

Statistical average quantities determined by the zero-up-crossing method, such as the significant wave height and period, is widely used in the description of ocean waves. The individual waves are numbered when the surface displacement crosses upward the zero-level, and the period is defined as the time interval between successive up-crossings of the zero-level and the wave height as the crest to trough height.

Before the wave analysis by the zero-up-crossing method, the mean sea level during observation is generally excluded from the out-put records. In the wave recorder on the JMA Ocean Data Buoy, however, this exclusion processing of the mean level is not made because of the limitation of data processing capability. In such a limited system, the drift of the mean level due to a minor shift of the electric or mechanical balance in a wave recorder exerts a significant influence on the estimation of the statistical average quantities of zero-up-crossing waves.

The drift results in a miscount of waves. A schematic explanation is shown in Fig. 1, in which the mean level (dashed line) deviates stationarily from the real zero level (solid line). The waves, nos. 1, 12, 16, 22, 24 and 32, whose heights of troughs are smaller than the values of drift D , do not intersect the zero level (solid line), and are not regarded as one wave. Therefore, the number of waves counted by the zero-up-crossing method decreases from 34 to 28 waves, and the measured average period apparently increases $34/28$ times the real period. The average wave height also increases because of a miscount of the small height waves.

In this paper, we derive theoretically the relations of the measured wave height and period to a stationary drift of the mean level as illustrated in Fig. 1 assuming the Rayleigh distribution for wave heights, and apply the results to correct the wave height observed by the JMA Ocean Data Buoy No. 6.

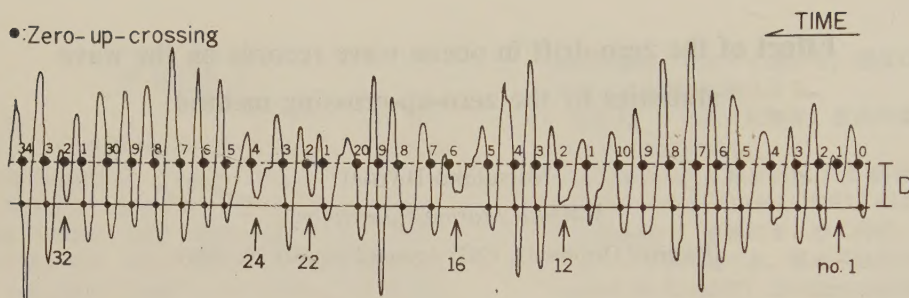


Fig. 1. Wave records with a stationary drift of the mean-level (dashed line) from the zero-level (solid line). Large closed circles indicate the up-crossings of the mean-level and small solid circles those of the zero-level.

2. Results

2.1. Theoretical results

We derive the relations of the measured average wave height and period of the highest one-n'th waves to a stationary drift of the mean level under the following two assumptions:

(i) The probability density distribution of wave height H follows the Rayleigh distribution derived by LONGUET-HIGGINS (1952) for a narrow band random waves:

$$P(h) = \frac{\pi}{2} h \exp\left(-\frac{\pi}{4} h^2\right), \quad h = \frac{H}{\bar{H}} \quad (1)$$

where $\bar{H}$ is the average wave height of all waves.

(ii) The crest is equal to the trough in height for each wave. In the subsequent analyses, all the quantities are represented in forms normalized by the real average period $\bar{T}$ and wave height $\bar{H}$ of all waves. The normalized quantities are designated by small letters, such as the period t , wave height h and the drift $d (=D/\bar{H})$.

When the mean level shifts from the zero level to d , the wave whose height is less than $2|d|$ does not exceed the zero level as illustrated in Fig. 1, and the probability that an individual wave is counted by the zero-up-crossing method becomes

$$P_d = \int_{2|d|}^{\infty} P(h) dh = \exp(-\pi d^2). \quad (2)$$

Since the expected number of waves during a constant time interval decreases at this rate, the measured average period of all the waves $\bar{t}(d)$ is given by

$$\bar{t}(d) = 1/P_d = \exp(\pi d^2). \quad (3)$$

The period $\bar{t}(d)$ is shown in Fig. 2 as a function of $|d|$. The measured period increases exponentially with the drift.

The average period of the highest one-n'th waves is equal to the average period of all waves $\bar{t}(d)$, if we assume that the period of individual waves is independent of the wave height.

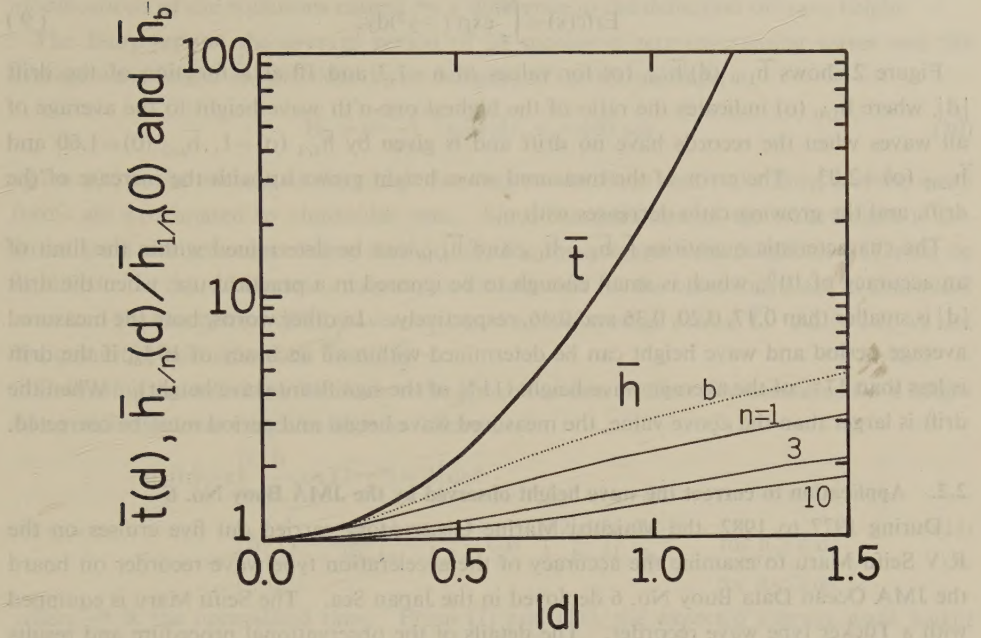


Fig. 2. Normalized average period $\bar{t}$, ratio of average wave height of the highest one- n 'th of all the waves to those for no-drift $\bar{h}_{1/n}(d)/\bar{h}_{1/n}(0)$, and $\bar{h}_b$ for the JMA buoy (dotted line) as function of drift $|d|$.

Next, we examine the average wave height of the highest one- n 'th waves $\bar{h}_{1/n}$. Since the wave height of an individual wave does not altered by the stationary drift, the probability distribution of the measured wave height $P_m(h)$ becomes

$$P_m(h) = \begin{cases} 0 & \text{for } h \leq 2|d| \\ P(h)/P_d = \frac{\pi}{2} h \exp \left\{ -\frac{\pi}{4} (h^2 - 4d^2) \right\} & \text{for } h > 2|d| \end{cases} \quad (4)$$

from (1) and (2). The expected wave height $\bar{h}_{1/n}$ is calculated from

$$\bar{h}_{1/n}(d) = n \int_Z^\infty h P_m(h) dh \quad (5)$$

where Z is determined from

$$\int_Z^\infty P_m(h) dh = \frac{1}{n} \quad (6)$$

and given by

$$Z = \frac{2}{\sqrt{\pi}} (\pi d^2 + \ln(n))^{\frac{1}{2}}. \quad (7)$$

Integrating (5), we obtain

$$\bar{h}_{1/n}(d) = \frac{2}{\sqrt{\pi}} [(\pi d^2 + \ln(n))^{\frac{1}{2}} + n \exp(\pi d^2) \text{Erfc}\{(\pi d^2 + \ln(n))^{\frac{1}{2}}\}] \quad (8)$$

where $\text{Erfc}(x)$ is the error function:

$$\text{Erfc}(x) = \int_x^\infty \exp(-y^2) dy. \quad (9)$$

Figure 2 shows $\bar{h}_{1/n}$ (d)/ $\bar{h}_{1/n}$ (o) for values of $n=1,3$ and 10 as a function of the drift $|d|$, where $\bar{h}_{1/n}$ (o) indicates the ratio of the highest one- n 'th wave height to the average of all waves when the records have no drift and is given by $\bar{h}_{1/1}$ (o)=1, $\bar{h}_{1/3}$ (o)=1.60 and $\bar{h}_{1/10}$ (o)=2.03. The error of the measured wave height grows up with the increase of the drift, and the growing ratio decreases with n .

The characteristic quantities $\bar{t}$, $\bar{h}_{1/1}$, $\bar{h}_{1/3}$ and $\bar{h}_{1/10}$ can be determined within the limit of an accuracy of 10% which is small enough to be ignored in a practical use, when the drift $|d|$ is smaller than 0.17, 0.20, 0.36 and 0.46, respectively. In other words, both the measured average period and wave height can be determined within an accuracy of 10%, if the drift is less than 17% of the average wave height (11% of the significant wave height). When the drift is larger than the above value, the measured wave height and period must be corrected.

2.2. Application to correct the wave height observed by the JMA Buoy No. 6

During 1977 to 1982, the Maizuru Marine Observatory carried out five cruises on the R/V Seifu Maru to examine the accuracy of the acceleration type wave recorder on board the JMA Ocean Data Buoy No. 6 deployed in the Japan Sea. The Seifu Maru is equipped with a Tucker type wave recorder. The details of the observational procedure and results were presented in HATORI (1983).

We made a comparison of wave data obtained on the Buoy to those on board the ship, and found that the periods and wave heights observed by the Buoy are considerably larger than those by the Tucker, as shown in Fig. 3. If we assume that the over-estimate in the recorder on the Buoy is due to the drift of the mean level in the measuring system, we can correct the wave height on the Buoy based on the theoretical results in 2.1, with some

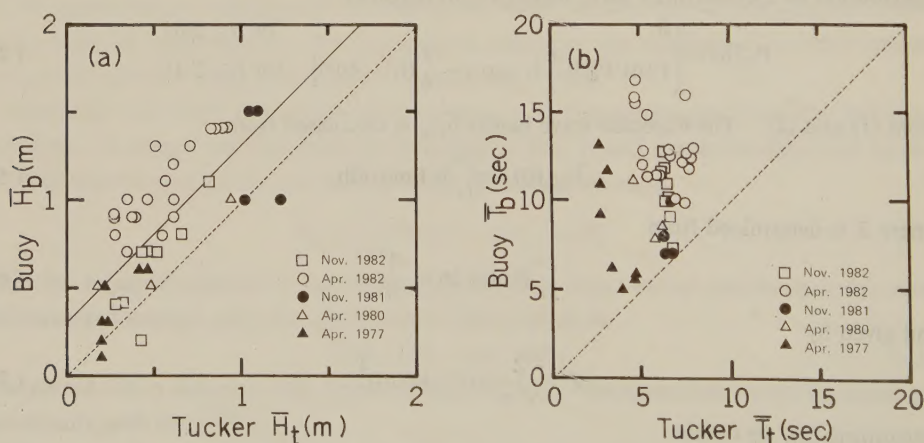


Fig. 3. (a) Relation of the periods obtained with the JMA Buoy No. 6 and the Tucker-type wave recorder of the R/V Seifu Maru. (b) Same as (a) except for the wave heights. A solid line in (a) indicates a regression line, $\bar{H}_b = 1.01 \bar{H}_t + 0.30$.

modifications of the equations caused by a difference in the definition of wave height.

The Buoy reports the average period of 20 successive zero-up-crossing waves and the average wave height $\bar{H}_b$ provided by an integration for 400 seconds,

$$\bar{H}_b = \pi \frac{1}{\tau_0} \int_0^{\tau_0} |\eta(\tau)| d\tau, \quad \tau_0 = 400 \text{ sec} \quad (10)$$

where $\eta(\tau)$ is the surface displacement detected on the Buoy and τ the time, and the wave forms are proximated by sinusoidal ones. Since the definition of the wave height is different from the zero-up-crossing method, (8) for the average wave height ($n=1$) must be modified. In the subsequent analyses, we assume that (a) the wave forms are in sinusoidal ones and (b) the period of all waves are equal to the average period $\bar{T}$. As in 2.1, we use the quantities normalized by $\bar{T}$ and $\bar{H}$.

Following the definition (10) and on the above two assumptions, the measured wave height of an individual wave is calculated as follows:

$$\begin{aligned} h_b(h) &= \pi \int_0^1 \left| \frac{h}{2} \cos(2\pi\tau^*) + d \right| d\tau^* \\ &= \begin{cases} h \left[\left(1 - \frac{4d^2}{h^2} \right)^{\frac{1}{2}} + \left\{ \frac{\pi}{2} - \cos^{-1} \left(\frac{2|d|}{h} \right) \right\} \frac{2|d|}{h} \right] & \text{for } h \geq 2|d| \\ \pi|d| & \text{for } h \leq 2|d| \end{cases} \end{aligned} \quad (11)$$

where τ^* is the normalized time. From (1) and (11), the expected average wave height obtained on the Buoy $\bar{h}_b$ is given by

$$\begin{aligned} \bar{h}_b(d) &= \int_0^\infty h_b(h) P(h) dh \\ &= \{ \pi + (2 - \pi) \exp(-\pi d^2) \} |d| + \frac{2}{\sqrt{\pi}} (1 + \pi d^2) \text{Erfc}(\sqrt{\pi} |d|) \end{aligned} \quad (12)$$

where $h_b(h)$ for $h \geq 2|d|$ is approximated by the power series of d/h to the second order.

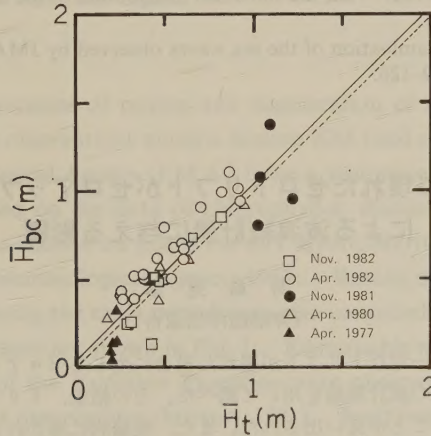


Fig. 4. Corrected wave height of the JMA Buoy No. 6 $\bar{H}_{bc}$ versus the measured wave height with the Tucker-type wave recorder $\bar{H}_t$. A solid line shows a regression line, $\bar{H}_{bc} = 1.00 \bar{H}_t + 0.04$.

As we have no facility to estimate the drift $|d|$, both the period and wave height can not be corrected simultaneously. We make only a correction of the wave height under the assumption that the true period to be obtained on the Buoy is equal to that measured by the Tucker type wave recorder $\bar{T}_t$. Substituting the value of $\bar{T}_b/\bar{T}_t (= \bar{t})$ into (3), we obtain the value of the drift normalized by the real average wave height $|d|$. Then the ratio of the measured wave height $\bar{H}_b$ to the real one $\bar{H}_{bc}$, that is, $\bar{h}_b = \bar{H}_b/\bar{H}_{bc}$, is evaluated from (12), and the corrected wave height, $\bar{H}_{bc}$, is obtained. In Fig. 4, $\bar{H}_{bc}$ is plotted against $\bar{H}_t$. The corrected wave heights $\bar{H}_{bc}$ agree reasonably well with the observation by the Tucker type wave recorder.

3. Conclusion

The drift of the mean level leads to an apparent increase of the average wave height and period of ocean waves calculated by the zero-up-crossing method. The errors of the measured average wave height and period exceed an accuracy of 10% which can not be ignored in a practical use, when the drift is larger than $0.20 \bar{H}$ and $0.17 \bar{H}$, respectively, where $\bar{H}$ is the real average wave height. In such cases, the correction of the over-estimated data using the present theoretical relations for a stationary drift must be useful.

Acknowledgement

The author wishes to express his greatest appreciation to Dr. Ichiro ISOZAKI of Meteorological Research Institute for his encouragement and advice in preparing the manuscript. The author is also indebted to the members of Marine Meteorological Division, Maizuru Marine Observatory, for their co-operation in the observations.

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波浪記録に現れたゼロドリフトがゼロアップクロス法 による波浪統計量に与える影響

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波浪記録に平均レベルの一定なドリフトが現れた場合に生じるゼロアップクロス法による波浪統計量の誤差について、波高の統計理論を用いて調べた。その結果、ドリフトが大きくなるにつれて測定波高と周期が増加することが見出された。また、理論的に導かれた測定値とドリフトとの関係を用いて、日本海6号ブイロボットによる波浪の観測値を検討した。

Planktological considerations of the Kuroshio Extension neighbouring Japan with emphasis on the abundance of coastal species

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and

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(Received June 14, 1983; Accepted January 20, 1984)

Abstract: Distributions of chlorophyll-a, diatoms, chaetognaths and larval plankton in the Section along 144°E, crossing the Kuroshio Extension, were studied. From the characteristics of plankton the Section was divided into three parts; namely, the northern cold water, the Kuroshio Extension and the southern oceanic water. Because of the change of the flow axis of the Kuroshio Extension, the arrangement of the three areas in the Section changed remarkably between the observations in October 1980 and in May 1981.

Plankton were abundant in number in the northern part of the Kuroshio Extension and in the cold water area, and were poor in number in the southern oceanic area. Judging from the species compositions of phyto- and zoo-plankton, the water of the "cold water area" in the Section consists of the mixture of the Oyashiro water, the Kuroshio water and the coastal water carried *in situ* by the Kuroshio Extension. This fact is seemed to be the reason of the richness in plankton population in this area.

From the occurrence of coastal species of diatoms and the larvae of the benthic brittle stars in the Section, it is concluded that the Kuroshio Extension transports a considerable amount of the coastal water near Japan.

1. Introduction

To investigate the processes of mixing and degeneration of matters in the Kuroshio, a series of oceanographic observations along a Section KM fixed on 144°E has been operated by the Japan Meteorological Agency (J.M.A.) twice a year since the autumn of 1980. The present studies are based on the data of chlorophyll-a, diatoms, chaetognaths and larval plankton sampled in the Section on board the R/V Ryofu Maru of J.M.A. in October 1980 and May 1981 (Japan Meteorological Agency, 1982). Results of the observations operated in the other sections during the same period were also consulted.

Locations of the Sections are shown in Fig. 1. Remarkable north and south fluctuations of the flowing course of the Kuroshio Extension were observed around Sec. KM during the period of the present observations (MUTOH, 1981). Positions of current axes determined from monthly mean water temperature at 100 m depth (J.M.A., 1980-81) are also shown in Fig. 1. According to MORIYASU (1971), Sec. KM is one of the areas where the meandering of the Kuroshio Extension markedly develops and its north and south shifting ranges

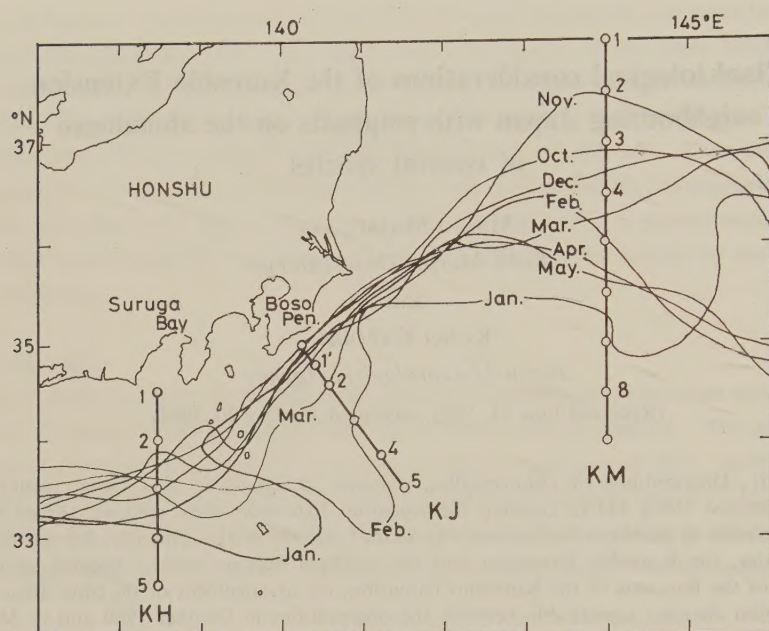


Fig. 1. Location of the Sections and Stations. Mean axes of the Kuroshio and its Extension determined from the monthly mean water temperature at 100 m depth (Japan Meteorological Agency, 1980-1981) are shown together.

between 35° and 38°N.

Planktological observations in the Kuroshio Extension neighbouring Sec. KM have been reported by many workers (MARUMO, 1955, 1956; OHWADA and ASAOKA, 1957; MARUMO et al., 1960; KAWARADA et al., 1966, 1968; SANO, 1966; KAWARADA and SANO, 1972). It has become clear that the warm water of the Kuroshio Extension and the northern cold water which border complicatedly each other in this region can be distinguished one from another by the characteristics of the plankton compositions, and that the plankton is far rich in number in the cold water region than in the south of the Kuroshio Extension. However, the populations and compositions of plankton in the seasons of spring and autumn have been unknown and their short-term changes caused by the fluctuations of the Kuroshio Extension have not been described before. In addition, the distribution of the concentrations of chlorophyll-a in autumn in this region is also studied for the first time.

The present study was carried out in the framework of the Kuroshio Exploitation Research (KER) programme promoted by the Science and Technology Agency of Japan.

2. Materials and methods

Concentrations of chlorophyll-a and phaeopigment in 250 ml sea water were determined by the fluorometric method. Samples were collected from 11 or 12 depths at each station, within the range of upper 300 m. Pigments were extracted by 85% acetone after filtered

with a glass fibre filter, then measured with a fluorophotometer. Details of the method is as described by KAWARADA and SANO (1972). Measurement was done by the authors and N. KUBO on board the R/V Ryofu Maru at 35 stations including 8 in the Sec. KM in October 1980 and at 13 stations including 7 in the Sec. KM in May 1981.

Diatom species in 500 ml sea water were identified and counted under a microscope after settled and concentrated with a centrifuge. Water samples were collected mainly from the surface, and at 10 stations in October 1980, subsurface samples were collected from 20, 60 and 100 m depths, respectively. Identification was done by K. KAROHJI, N. KUBO and M. IMAI. Total of 49 diatom samples including 20 in the Sec. KM in October 1980 and of 13 diatom samples including 7 samples in the Sec. KM in May 1981 were examined.

Zooplankton were collected by vertical hauls from 150 m to the surface with a Norpac net, having a mesh size of 0.3×0.3 mm and equipped with a flow-meter and a depth meter. Chaetognaths species were identified and counted under a microscope, and then wet weight of the samples was measured. Larval plankton were also counted in May 1981. Identification was done by M. MATSUZAKI. Of 19 zooplankton samples 8 samples were collected in the Sec. KM in October 1980, and of 13 zooplankton samples 7 samples in the Sec. KM in May 1981.

3. Results and discussion

1) Chlorophyll-a

Distributions of temperature and salinity at the depth of 100 m in October 1980 are shown in Figs. 2-a and -b, respectively. Axes of the Kuroshio and the Kuroshio Extension nearly correspond to the isotherm of 20°C and the isohaline of 34.6. Values of chlorophyll-a integrated from the surface to 200 m depth are shown in Fig. 3. Chlorophyll-a is rich in concentration along the northern periphery of the Kuroshio, and especially it is more than 70 mg/m^2 in the lower temperature and less haline water which is situated near the entrance of Suruga Bay and in the area south of Boso Peninsula. This rich area extends eastwards along the Kuroshio, but not reach Sec. KM where integrated values are less

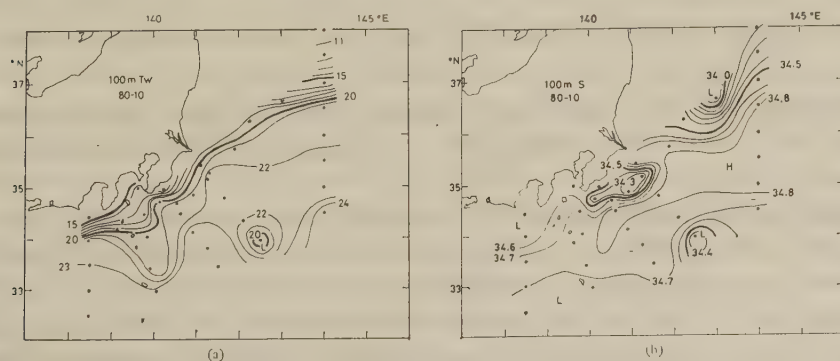


Fig. 2. Distribution of water temperature (a) and salinity (b) at 100 m depth, in October 1980.

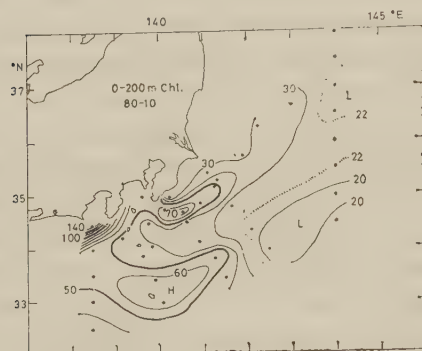


Fig. 3. Distribution of chlorophyll-a integrated from the surface to 200 m depth, in October 1980.

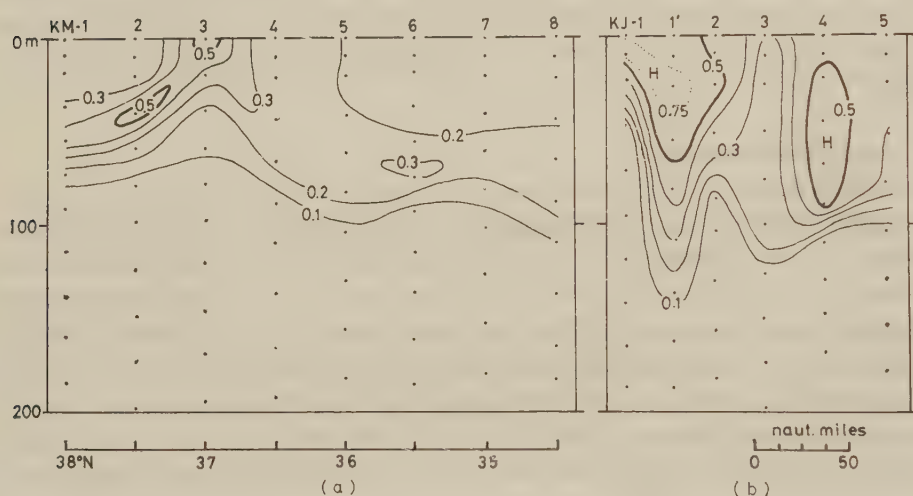


Fig. 4. Vertical distribution of chlorophyll-a in Sec. KM(a) and in Sec. KJ(b), in October 1980.

than 30 mg/m^2 . A water mass of lower temperature and lower salinity was found around at 34°N , 142°E , and it was considered not to be of coastal origin because of poor quantity of chlorophyll-a.

Vertical distributions of chlorophyll-a in Sec. KM and KJ in October 1980 are shown in Fig. 4-a and -b, respectively. In Sec. KM (Fig. 4-a), a chlorophyll-a maximum layer containing more than $0.4 \mu\text{g/l}$ in concentration is seen at the stations from KM-1 to KM-3. The subsurface chlorophyll-a maximum lies at 60 m depth at the northernmost station, KM-1 (38°N), and at shallow depths toward the south. At KM-3 it appears in the surface layer where the northern cold water adjoins the Kuroshio Extension. Below 100 m depth concentrations of chlorophyll-a are almost negligible, being less than $0.1 \mu\text{g/l}$, in Sec. KM.

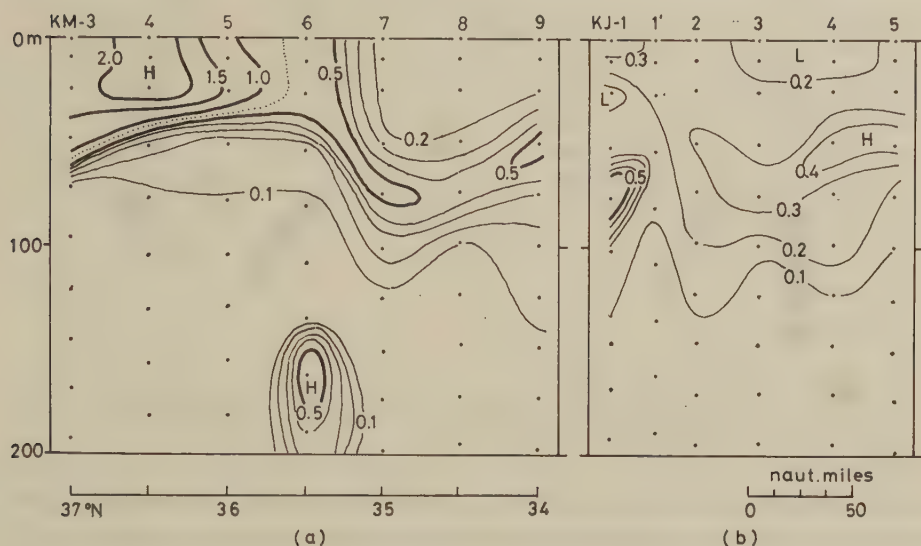


Fig. 5. Vertical distribution of chlorophyll-a in Sec. KM (a) and in Sec. KJ (b), in May 1981.

On the other hand, relatively high chlorophyll-a contents are observed in the deeper layer than 100 m depth at KJ-1 and KJ-3.

Vertical distributions of chlorophyll-a in Sec. KM and KJ in May 1981 are shown in Figs. 5-a and -b, respectively. The boundary between the northern cold water and the Kuroshio Extension is located near KM-6 (35.5°N), farther south than that in October 1980. In comparing with both years, chlorophyll-a increased in concentration sharply in May 1981. Chlorophyll-a maxima are present at the surface to the north of the Kuroshio Extension, and the highest value more than 2.0 $\mu\text{g/l}$ is found at KM-4 (36.5°N). Integrated values of chlorophyll-a from the surface to 200 m depth amounted to more than 60 mg/m^2 to the north of 35.5°N, and to more than 100 mg/m^2 to the north of 36.5°N. High chlorophyll-a concentrations are found in the depths of 160 m to 190 m at KM-6. It seems that the surface water of the Oyashio might submerge to these depths at KM-6, because the water is characterized by low temperature, low salinity, and richness of nutrients, chlorophyll-a and dissolved oxygen in concentrations.

KAWARADA and SANO (1972) studied chlorophyll-a and phaeopigments in May 1969 along 144°E, being the same area with Sec. KM. They observed high chlorophyll content in the Kuroshio Extension and in the northern cold water. The pattern of vertical distribution of chlorophyll in May 1981 is nearly similar to that in 1969, except the above-mentioned deep water with high chlorophyll-a concentration at the boundary between the Kuroshio Extension and northern cold water.

There was not so large difference between the distributional patterns of the pigment in October 1980 and in May 1981 in Sec. KJ. In Sec. KM, however, the distributional pat-

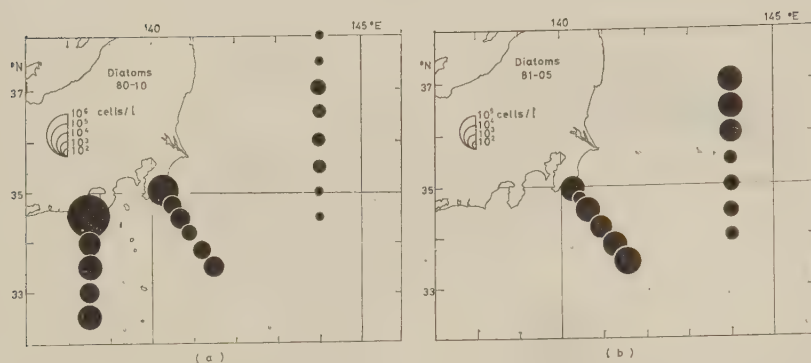


Fig. 6. Distribution of the population of diatoms (cells/l) at the sea surface, in October 1980 (a) and in May 1981 (b).

tern of the pigment changed remarkably because of the change of location of Kuroshio Extension and of the seasonal change of phytoplankton in the northern cold water area.

2) Diatom population

Distribution of cell numbers of diatoms per liter in the surface water in October 1980 and in May 1981 are shown in Figs. 6-a and -b, respectively. In October 1980, distributional pattern of diatom populations in the south of Suruga Bay (Sec. KH) and in the southeast of Boso Peninsula (Sec. KJ) closely resemble each other. In Sec. KH, cell numbers are large, exceeding $10^6/l$ in the coastal water and about 10^4 in the Kuroshio and southern offshore water. Also in Sec. KJ, they are about 7×10^4 cells/l in the coastal water and a little smaller, at a level of 10^3 in the Kuroshio. Subsurface data show that in Sec. KH cell numbers are one thousandth of surface below the thermocline in the coastal water, while homogenous in the upper 100 m in the Kuroshio and southern offshore water, and also in Sec. KJ they are one hundredth of surface at 20 m through 100 m in the coastal water, and homogenous in 0-60 m and below it one tenth in the Kuroshio. In Sec. KM, on the other hand, cell numbers are at a very low level of 10^2 , except the larger populations of 10^3 in the surface of the northern part of the Kuroshio Extension and 4×10^3 at the 60 m depth of KM-1 in the northern cold water, both coinciding with the chlorophyll-a maximum layer. It is noticed along the Kuroshio and the Kuroshio Extension the cell numbers show a tendency to decrease eastwards as it goes downstreams.

In May 1981, along Sec. KJ, cell numbers were about the level of $10^4/l$, increased in the offshore waters and decreased in the coastal water, compared with the last autumn. In Sec. KM, they increased to the level of 10^4 in the northern cold water, but remained unchanged and at the levels of 10^2 to 10^3 in the Kuroshio Extension.

3) Species composition of diatoms

The characteristics of diatom communities in the waters corresponding to the present

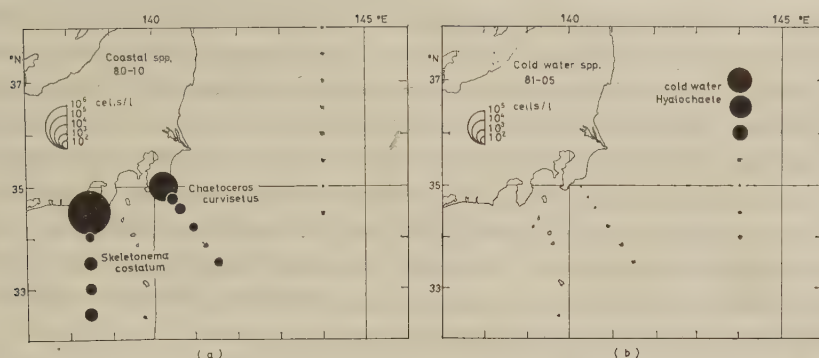


Fig. 7. Distribution of the indicator species of diatoms; the coastal water species in October 1980 (a) and the cold water species in May 1981 (b).

study were generally described by KAWARADA (1965) and KAWARADA et al. (1966, 1968). Indicator species of water masses were studied by MARUMO (1955, 1957) and MARUMO et al. (1961). OHWADA and ASAOKA (1963) and SANO (1966) studied the Kuroshio Extension applying several indicator species. In the present observations, the composition of diatom populations changed extremely between the two seasons.

October 1980

Two coastal diatoms, *Skeletonema costatum* and *Chaetoceros curvisetus*, exceedingly dominated at the coast of Honshu; the former occupied 70% of total cell numbers at KH-1 and the latter 77% at KJ-1 (Fig. 7-a). Both species were also found in the offshore water but in far less quantities, one thousandth in Sec. KH and one hundredth in Sec. KJ. On the other hand, in the Kuroshio and southern offshore water of both Sec. KH and KJ, temperate species of subgen. *Hyalochaete*, gen. *Nitzschia* and *Bacteriastrum* were widely prevalent, while ratios of the indicator species of the Kuroshio such as oceanic species of gen. *Rhizosolenia* and subgen. *Phaeoceros* were small. In the Kuroshio Extension and southern oceanic water of Sec. KM, warm oceanic species of *Rhizosolenia* and *Phaeoceros* were found in high ratios and also species number were large. Among them, *Rhizosolenia* reaches as high as 40% in the Kuroshio Extension. Throughout Sec. KH, KJ and the Kuroshio Extension in KM, composition of subsurface diatom populations were almost common with those at the surface water. In the northern cold water, though in small number, these oceanic diatoms were also found along with the major constituents of this region such as gen. *Nitzschia*, *Thalassionema* and *Hyalochaete*. Differing from that in the surface water, a large population was counted at 60 m depth of KM-1 and it was dominated by cold water diatoms such as *Chaetoceros radicans* etc., while subtropical species, *C. messanensis* was also found in it. These facts indicate that the Kuroshio water are mixed with the northern cold water to a certain extent.

May 1981

In Sec. KJ, temperate species of *Hyalochaete* and *Nitzschia* dominated in the coastal and Kuroshio water, while oceanic species of *Rhizosolenia* were prevalent in the southern off-

shore water. In Sec. KM, diatom compositions changed remarkably from the last autumn. Oceanic diatoms such as *Rhizosolenia*, *Hemiaulus* etc. dominated in the southern oceanic water as in Sec. KJ. Several species of coastal diatoms, on the other hand, were found in the Kuroshio Extension to a considerable extent. This fact seems to indicate that the Kuroshio Extension is carrying away considerable amount of the coastal water from Japan. Diatom compositions in the northern cold water were in sharp contrast to that of the other areas. Cold-water-preferring species of *Hyalochaete* dominated as shown in Fig. 7-a, along with the peculiar coastal species. From the prevalence of above-mentioned cold water species, it is clear that the Oyashio water advanced southward to 36°N, accompanied with the change of the meandering of the Kuroshio Extension.

The remarkable changes of populations and compositions of diatoms observed in Sec. KM seems to owe largely to the change of the Kuroshio Extension, and besides, it may also owe to the remarkable seasonal change of the plankton itself.

4) Wet weight of net plankton

Distributions of wet weight of net plankton in October 1980 and in May 1981 are shown in Figs. 8-a and -b, respectively. In October 1980 (Fig. 8-a) in Sec. KM and KJ, the wet weight were considerably large, being more than 100 mg/m³ along the northern edge of the Kuroshio, while they were less than 40 mg/m³ in the other areas. Such a pattern of distribution is similar to that of chlorophyll-a and diatoms. In Sec. KM, however, high values of wet weight were observed in the northern cold water, where the small populations of phytoplankton are present. In May 1981 (Fig. 8-b), distributional pattern is nearly the same as that in October 1980 in Sec. KJ. In Sec. KM, wet weight increased in the northern cold water, which extended to the south of 35°N accompanied with southward shift of the Kuroshio Extension. The highest value of wet weight reached up to 197 mg/m³ at KM-3, which was three times higher than that in October 1980, because of the abundance of copepods.

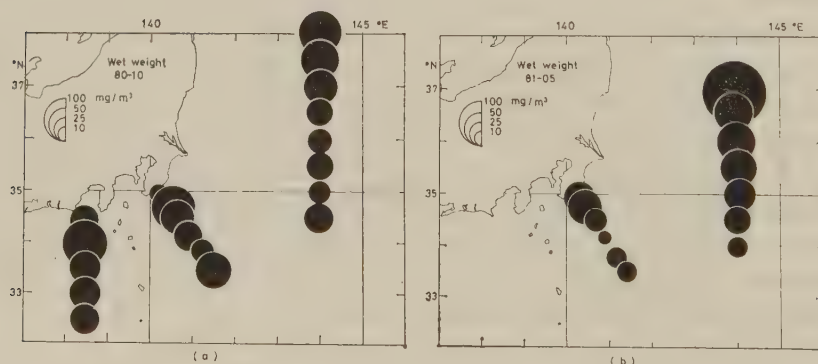


Fig. 8. Distribution of wet weight of net plankton (mg/m³), in October 1980 (a) and in May 1981 (b).

5) Species composition of chaetognaths

Distribution of chaetognaths in this region were generally described by BIERI (1959), KAWARADA et al. (1966, 1968) and NAGASAWA and MARUMO (1973). Indicator chaetognath species of the water masses were studied by KITOU (1966), MATSUZAKI (1975) and KURODA (1977).

Distribution of the typical indicator species in October 1980 and in May 1981 are shown in Figs. 9-a and -b, respectively. Following species were chosen for the indicators of water masses: *Sagitta elegans* for the Oyashio water, *S. nageae* and *S. crassa* f. *naikaiensis* for the coastal water of Japan, *S. hexaptera*, *S. lyra*, *S. pseudoserratodentata*, *Pterosagitta draco* and *Krohnitta subtilis* for the oceanic warm water. In the figures, each group of indicator species is shown by different marks, and the individual numbers of each group per 10 m³ of water, except the Oyashio group, is shown by the various size of circles.

In October 1980 (Fig. 9-a), the coastal water species (white circle) were restricted in the coastal area, north of the Kuroshio. Oceanic species (black circle) prevailing in the water south of the Kuroshio were also found in the coastal area, though in small number. The Oyashio water species (mark **) was found in the stations north of 37.5°N, indicating the extent of Oyashio water there.

In May 1981 (Fig. 9-b), both coastal and oceanic water species were found at all stations in Sec. KJ, indicating that both waters were mixed with each other throughout Sec. KJ. In Sec. KM, however, these two groups co-existed only at KM-6 and KM-7. The Oyashio water species prevailed at the stations north of 35°N, which were distributed in the area north of 37°N in October 1980. It is noticeable that the coastal water species increased in occurrence and the oceanic water species decreased in number in spring.

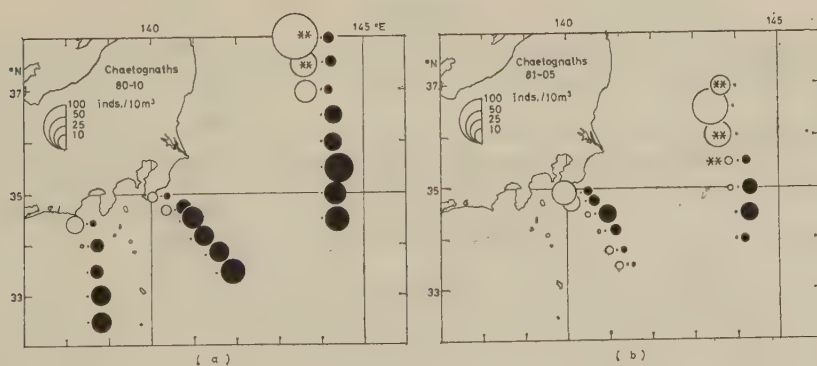


Fig. 9. Distribution of the indicator species of chaetognaths; in October 1980 (a) and in May 1981 (b).

- : coastal water species (*Sagitta nageae*, *S. crassa* f. *naikaiensis*)
- : Oceanic warm water species (*S. hexaptera*, *S. lyra*, *S. pseudoserratodentata*, *Pterosagitta draco*, *Krohnitta subtilis*)
- ** : Oyashio water species (*S. elegans*)

Temperate species such as *S. enflata*, *S. pacifica* and *S. minima* were found in high ratios throughout the areas investigated. In the northern cold water in Sec. KM, the total individual numbers of chaetognaths in October 1980 were larger than those in May 1981, owing to the abundance of a coastal water species, *S. nageae*. In the other areas, on the other hand, chaetognath population was larger in May, owing to the predominance of the above-mentioned temperate species.

6) Larval plankton

MARUMO and KITOU (1956) and MARUMO (1957) studied the Kuroshio Extension referring to the planktonic larvae of benthic animals. They concluded that the current can be traced from the coast of Japan to the Eastern Pacific Ocean by the larval plankton as the indicators. The same method was used in the present study.

Larval plankton, especially the larvae of brittle stars, were found in large number in May 1981, though only a few in October 1980. Distribution of ophiopluteus larvae of brittle star, Order Ophiuræ, adult form of which lives on the sea-bed of coastal area, is shown in Fig. 10. Ophioplutei were found at three coastal stations in Sec. KJ and were at stations north of 35°N in Sec. KM, especially abundant in number in the Kuroshio Extension.

As Sec. KM is situated above the Japan Trench, beyond 6000 m in depth, it is certain that ophioplutei found in the Section might be carried by the Kuroshio Extension.

4. Conclusion

From the distribution of chlorophyll-a, and compositions of diatoms and chaetognaths the Section KM can be divided in three parts; namely the northern cold water, the Kuroshio

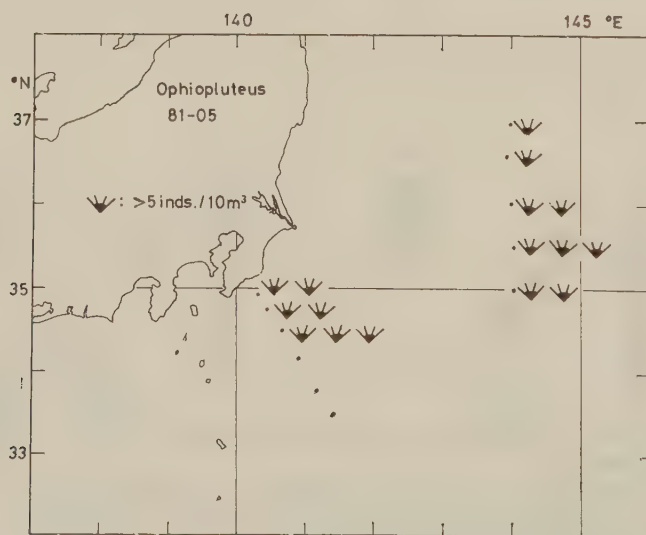


Fig. 10. Distribution of the ophiopluteus larvae of brittle stars in May 1981.

Extension and southern oceanic water. The arrangement of these three areas is changed remarkably by the change of the Kuroshio Extension.

On account of the fact that the phytoplankton population were far more abundant in spring than in autumn, it can be said that the "cold water" in the Section have the same characteristic as the subarctic water. It can also be said that the "southern oceanic water" in the Section have a similar characteristic to the off-shore warm water in the western Pacific, from the fact that the populations and species compositions of plankton did not change considerably between autumn and spring.

Judging from the species compositions of phyto- and zoo-plankton, the water of the "northern cold water area" in the Section consists of the mixture of the Oyashio water, the Kuroshio water and the coastal water near Japan carried by the Kuroshio Extension. This fact might seem to be the reason of the richness in plankton population in this area.

From the occurrence of coastal species of diatoms and larvae of the benthic brittle stars in the Section, it is obvious that the Kuroshio Extension transports a considerable amount of the coastal water near Japan.

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本州東方の黒潮続流と沿岸プランクトンの分布

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黒潮続流域の 144°E に沿った定線 (KM) において 1980 年 10 月および 1981 年 5 月に実施した海洋観測のうち、動植物プランクトンおよびクロロフィル a 量の分布について考察した。

動植物プランクトン量および種組成から、KM 線は、黒潮続流域、それ以北の冷水域および以南の外洋水域の三つに大別される。1980 年秋季と 1981 年春季における三水域の配置は大きく異り、黒潮続流の蛇行による位置の変動が著しいことを示している。

プランクトン量は冷水域から黒潮続流域の北寄りの部分にかけて顕著に多く、南の沖合域では少い。冷水域では秋季に比べ春季に植物量が著しく多く、北方水域共通の特徴をみせている。これに反し南方の沖合水域では春秋の差は少く、西太平洋の外洋水の傾向と共通している。

種組成からみて、KM 線上にみられる「冷水域」は、親潮水、黒潮続流に伴って運ばれたと思われる日本の沿岸水および黒潮水が混合した水域となっており、このことがプランクトンの生産が大きい原因と思われる。

沿岸性のプランクトン、特に春季における沿岸性ケイソウ類および沿岸動物の浮遊幼生の分布から、黒潮続流はかなりの量の沿岸水を本州東方沖へ運び去っていることが明らかとなった。

Relation between variation of the Kuroshio and the distribution of planktonic chaetognaths in the waters south of Japan

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Abstract: Distributions of two chaetognath species, *Sagitta nage* and *Pterosagitta draco*, collected in the Section G in the waters south of Japan on board the R/V Shumpu Maru of the Kobe Marine Observatory in the period from 1972 to 1980 were studied.

The distributional areas of *S. nage*, a coastal species, and *P. draco*, an off-shore species, are separated by the Kuroshio in the region investigated and change remarkably by the meandering of the current.

There was a time lag of about one season between the distributional patterns of chaetognaths and those of the oceanographical conditions. It seemed that the favorable conditions on water temperature and salinity to maintain the dense chaetognath population may be absent in winter in the area investigated.

From the unusual occurrence of the two species and the current patterns decided with GEK, it was proved that the coastal and offshore water are mixed through the Kuroshio by the developed vortex or by the countercurrent surrounding a cold water mass formed by the meandering of the Kuroshio.

1. Introduction

Individual numbers of chaetognath species at nine stations in the Section G south of Honshu have been recorded seasonally by the Kobe Marine Observatory since May 1972 (Japan Meteorological Agency, 1973-1981). In the Section G, situated in 135°15'E between 33°30' and 29°30'N, the Kuroshio flows eastward across the Section along the southern coast of Japan. During the period from March 1976 to September 1979 the meandering of the Kuroshio was observed in this area and the axis of the Kuroshio was located at the southern part of the Section. (Kobe Marine Observatory, 1976-1980) (Fig. 1).

The main purpose of the present studies is to get the distributional patterns of chaetognaths in relation to the meandering of the Kuroshio. In addition, the mixing of coastal and oceanic water is also studied by the characteristic occurrence of chaetognaths. FURUHASHI (1959, 1961) and KURODA (1973, 1976, 1977, 1980) studied the general distributions and the seasonal changes of chaetognaths in this area and they found some indicator species of water masses.

This study was carried out in the framework of the Kuroshio Exploitation Research Programme promoted by the Science and Technology Agency of Japan.

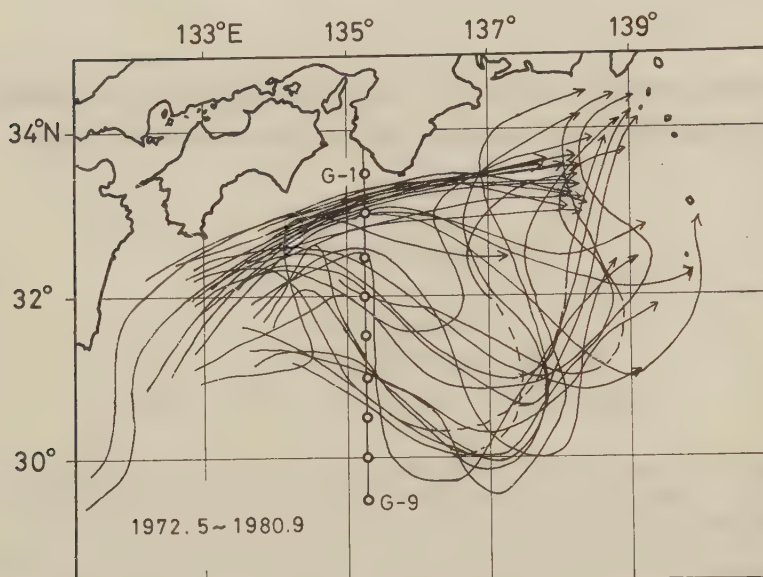


Fig. 1. Locations of the sampling stations in the Section G and the axes of the Kuroshio determined with GEK during the period from May 1972 to September 1980.

2. Materials and methods

A Norpac net with mouth diameter of 45 cm and mesh of 0.3×0.3 mm was hauled vertically from 150 m depth to the sea surface at every station. A depth meter and a flow meter were attached to the net.

Total number of 283 samples were collected during the period from May 1972 to September 1980 on board the R/V Shumpu Maru, 373 tons in gross tonnage, which belongs to the Kobe Marine Observatory. Microscopic examination for all samples to count individual numbers of chaetognaths by species was carried out, then the wet weight of the zooplankton samples were measured. Coelenterates, ctenophores, annelids, molluscs and extremely large arthropods were removed before weighing. Chaetognaths species were identified and counted by K. KURODA before 1976, by K. FURUHASHI from 1977 to 1978 and by M. IMAI, thereafter.

Among 19 species of chaetognaths in occurrence, *Sagitta nage* and *Pterosagitta draco* were selected for the studies on the changes of the distribution in time and space because they were found very commonly in the area investigated and were well-known as the indicator species of the water masses; the former for the coastal water and the latter for the oceanic warm water in this region (KURODA, 1976, 1977; MATSUZAKI, 1975).

Positions of the axis of the Kuroshio determined with GEK at every station are shown in Fig. 1.

3. Results

1) Wet weight of zooplankton

Yearly change of the biomass in terms of wet weight of the zooplankton sample at each station is shown in Fig. 2 where a bold broken line indicates the positions of the axis of the Kuroshio—the same shall apply in the following five figures. Until 1975, corresponding to the period of the so-called straight flow of the Kuroshio, large biomasses, being more than 50 mg/m^3 are limited in the northern coastal area and small biomasses, being less than 20 mg/m^3 , are observed in the wide area south of the Kuroshio. In the period from 1976 to 1979 which corresponds to the so-called meandering period of the Kuroshio, large biomasses are found in the oceanic region. The distribution of biomasses in 1980 to 1981 shows the same pattern as in the period from 1972 to 1975, when the Kuroshio returned to the straight flow pattern.

The fluctuation of the biomasses on a small scale is also found during the period from 1977 to 1979, corresponding to the fluctuation of the axis of the Kuroshio.

Small biomasses are also found in the northern coastal areas in the meandering period of the Kuroshio. These areas coincide with the countercurrent of the Kuroshio which flows westward near the coast of Kii Peninsula.

2) Total individual numbers of chaetognaths

The seasonal change of chaetognaths is shown in Fig. 3. Dense populations of chaetog-

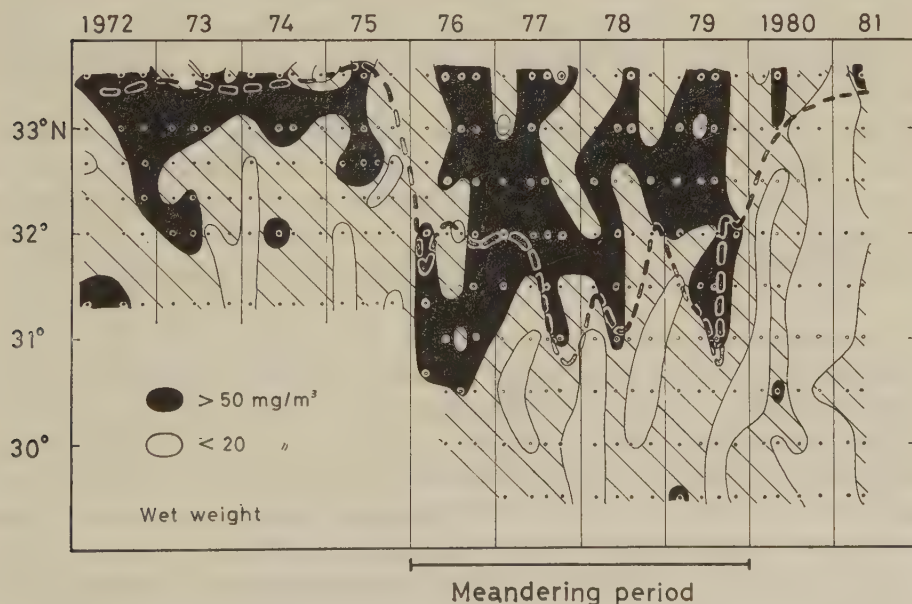


Fig. 2. Isopleths of wet weight of zooplankton. A bold broken line denotes the axis of the Kuroshio determined with GEK. A mark ● denotes the sampling stations.

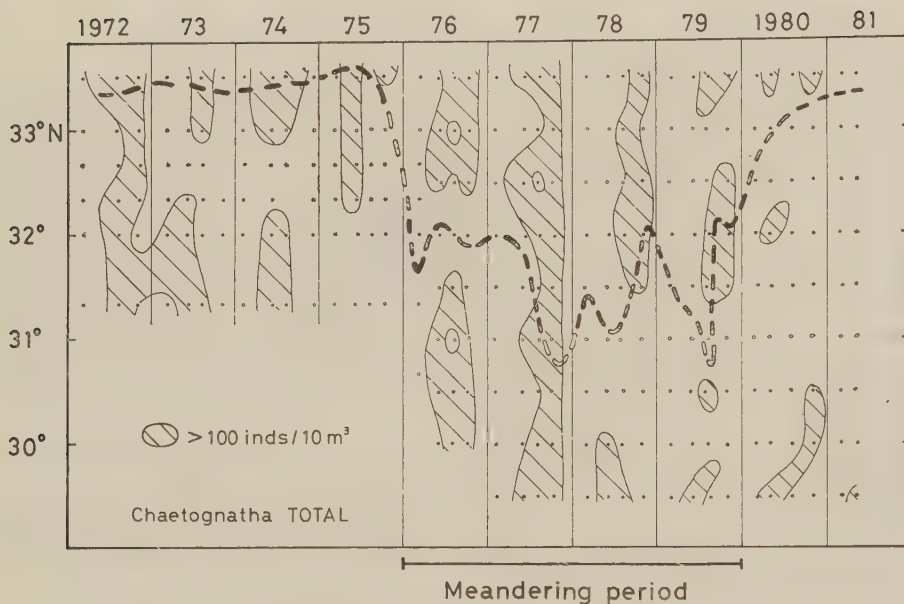


Fig. 3. Isopleths of total individual numbers of chaetognaths. Meanings of a broken line and a mark ● are the same as in Fig. 2.

naths is distributed in the north and the south areas of the Kuroshio as if they are separated by the current. These areas undergo a change in size corresponding to the meandering of the Kuroshio. There is a wide difference in species composition of chaetognaths between both areas.

Population of chaetognaths increases in summer and decreases in winter. This seasonal change is remarkable in coastal area where it varies from several individuals per 10 m³ of sea water in winter to about 200 inds./10 m³ in summer, but the change is less notable in the off-shore area. Population of chaetognaths shows its maximum in 1977 and then it seems to decrease, but its relationship to the sea condition is not recognized.

3) *Sagitta nage* and *Pterosagitta draco*

Yearly changes of individual numbers of *S. nage* and *P. draco* are shown in Figs. 4-a and -b, respectively. Both species show remarkable seasonal change.

S. nage increases in number in spring and summer and decreases in winter. The distributions of the species are mostly limited in the coastal region, north of the Kuroshio. They spread to the southern area during the meandering period of the Kuroshio. They exceptionally occurred in south of the Kuroshio in 1974 and 1975.

P. draco increases in number in summer and autumn and decreases in winter. Its distributions are mostly limited in the off-shore region, south of the Kuroshio. During the meandering period of the Kuroshio, *P. draco* occurs far south off from the coast. Some

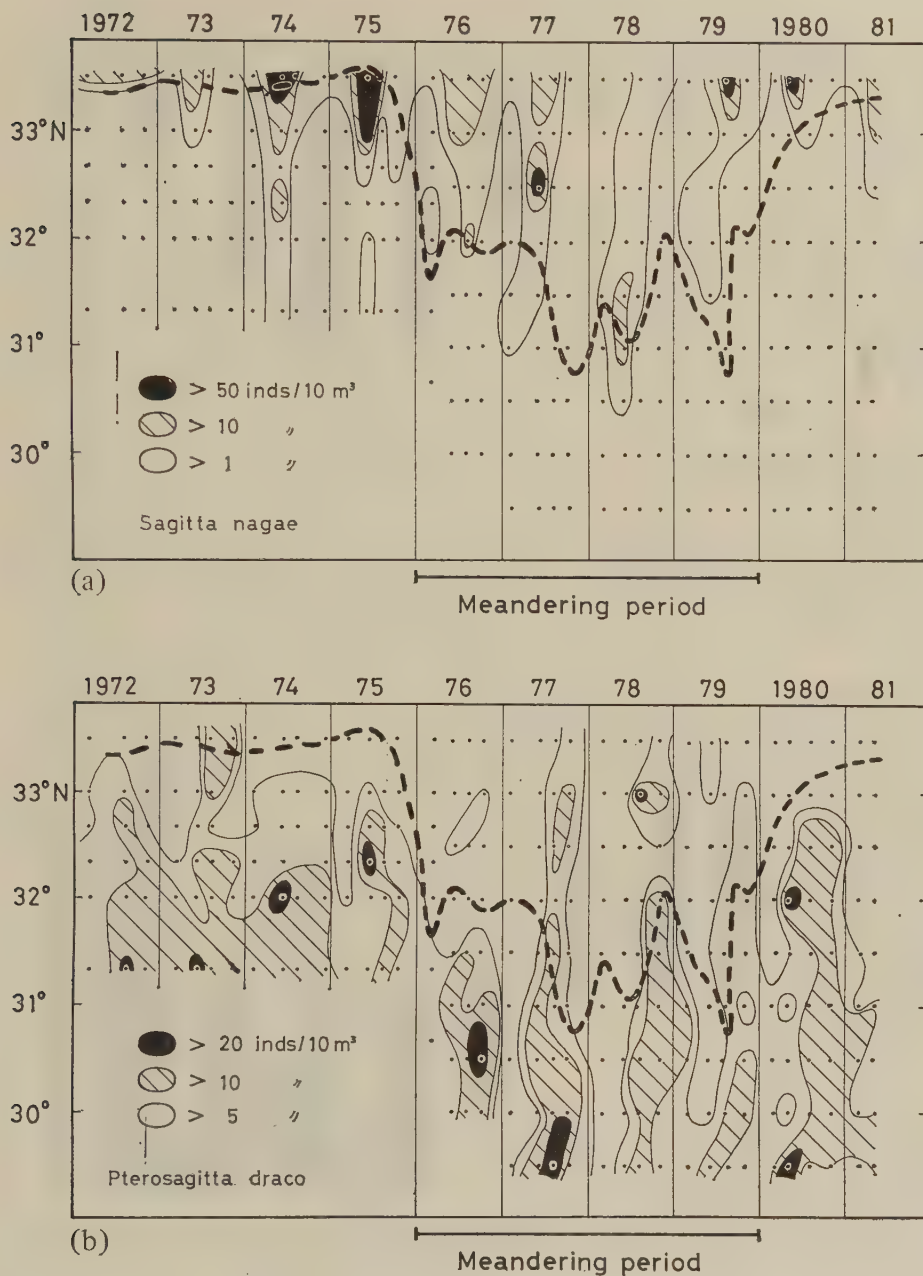


Fig. 4. Isopleths of population of *Sagitta nagae* (a) and *Pterosagitta draco* (b). Meanings of a broken line and a mark ● are the same as in Fig. 2.

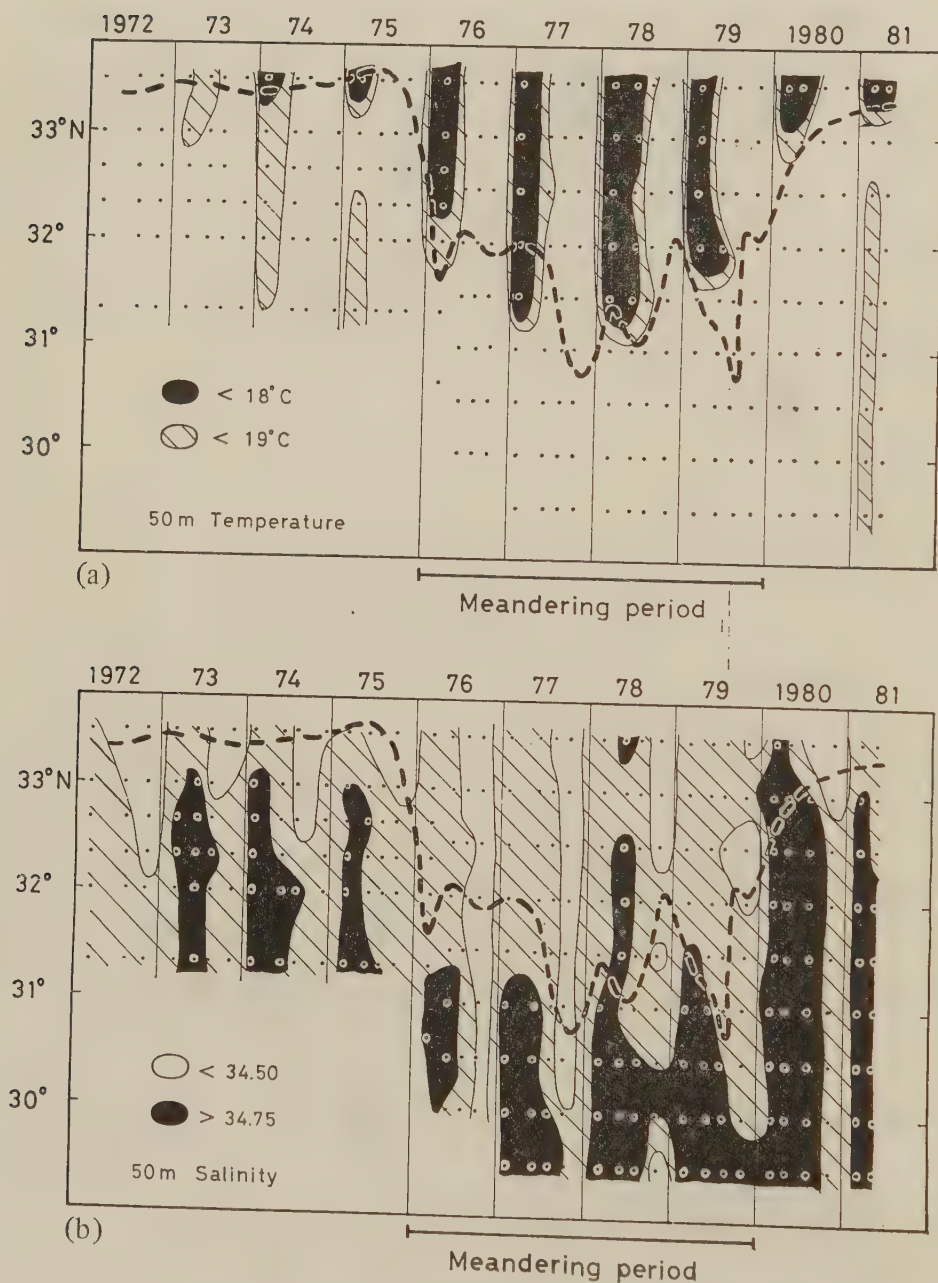


Fig. 5. Isopleths of water temperature (a) and salinity (b) at the depth of 50 m. Meanings of a broken line and a mark ● are the same as in Fig. 2.

exceptional occurrence of this species is also seen in the coastal area.

The distributions and the yearly changes of *S. lyra*, *S. hexaptera*, *S. pseudoserratodentata* and *Krohnitta subtilis* resemble to those of *P. draco*.

4. Discussion

1) Comparison with water temperature and salinity

Seasonal changes of water temperature and salinity at various depths such as the sea surface, 50 m, 100 m, and of the values of them integrated from the surface to 50 m, 100 m and 150 m depth are investigated because the samplings are made by vertical hauls of the net from 150 m depth to the sea surface and the diurnal vertical migration of chaetognaths can be considered (NAGASAWA and MARUMO, 1975). Figs. 5-a and -b show the changes of water temperature and salinity at 50 m depth which seem to have the best correspondence to the changes of chaetognaths.

Comparing Fig. 4-a with Fig. 5-a it can be said that the distributional patterns of water temperature below 18°C and those of the population of *S. nagae* resemble each other to some extent. However, the low temperature below 18°C is observed in winter, though the dense population of *S. nagae* occurs in spring. Consequently, it seems that there is a time lag of a season between the distributional patterns of them. Comparing Fig. 4-b with Fig. 5-b, the similar relationship between the distributional patterns of salinity above 34.75 and those of the population density of *P. draco*, is also seen.

At the depth of 50 m, water of temperature below 18°C is restricted in the northern area of the Kuroshio in winter and of salinity above 34.75 is situated in the southern area of the Kuroshio in winter and spring. *S. nagae* and *P. draco* occur in the coastal and the off-shore regions, respectively, showing the dense populations in the seasons from spring to summer and from summer to autumn, respectively. Therefore, the disagreement in time between the distributional patterns of these species and those of the oceanographic conditions seems to be due to the proper succession of the species mentioned above.

If temperature and salinity are the most important factors to maintain the populations of chaetognaths in the area investigated, it seems that the favorable conditions on temperature and salinity to support the dense population of chaetognaths may be scarce in winter and these two species may survive only in a restricted area. Then distribution of

Table 1. Ranges of water temperature (°C) and salinity in which more than 10 inds./10 m³ of *Sagitta nagae* and *Pterosagitta draco* occurred (1972–1981).

	winter	spring	summer	autumn
(a) Water Temperature				
<i>S. nagae</i>	—	18–21	20–21	—
<i>P. draco</i>	—	20–22	22–26	24–28
(b) Salinity				
<i>S. nagae</i>	—	34.60–34.75	34.21–34.70	—
<i>P. draco</i>	—	34.75–34.90	34.50–34.85	34.30–34.75

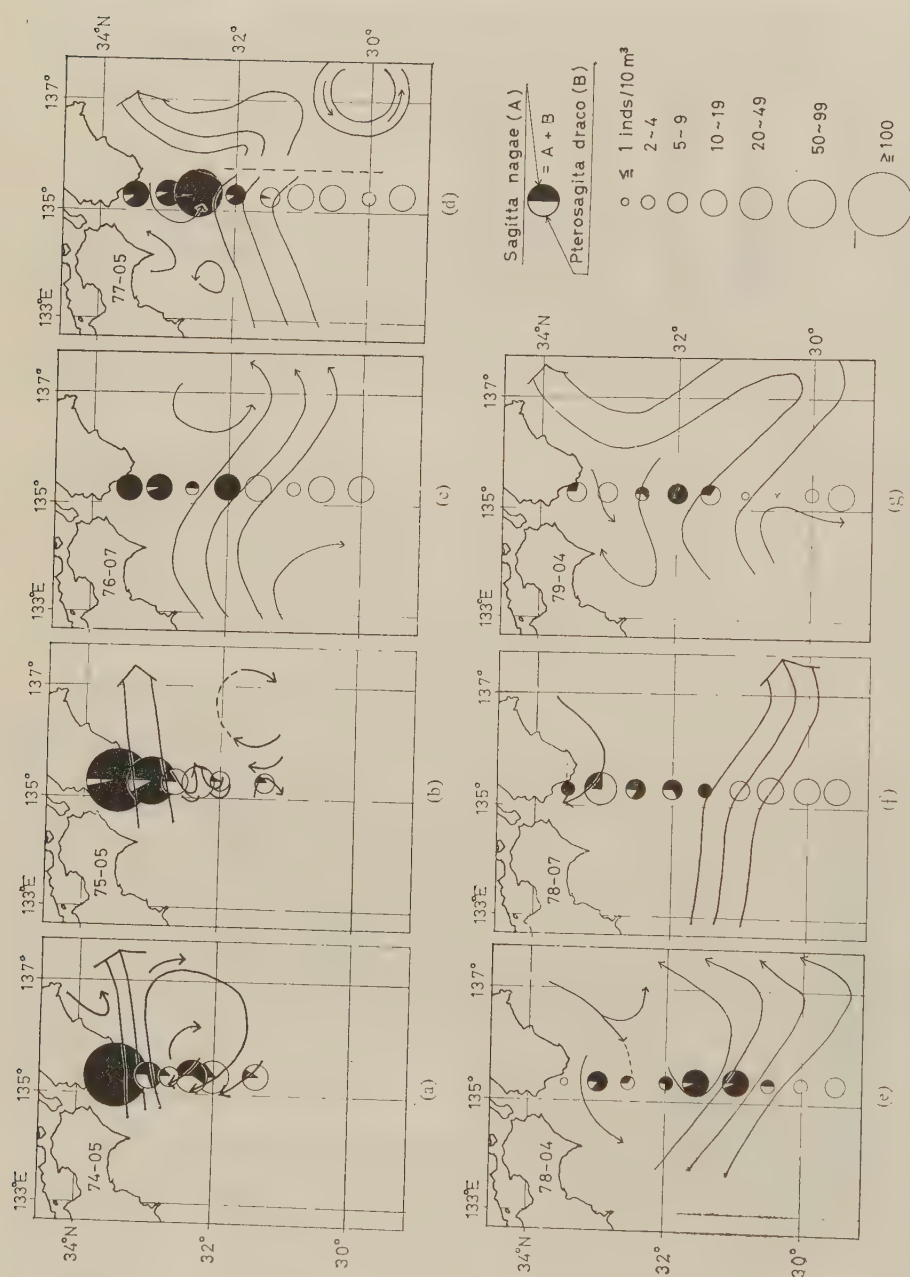


Fig. 6. Some cases of the unusual occurrence of *Sagitta nageae* and *Pterosagitta draco* and the currents determined with GEK. (a) May 1974, (b) May 1975, (c) June 1977, (d) May 1978, (e) April 1979, (f) June 1978, (g) April 1979, (h) June 1979.

these environmental factors in winter when the chaetognath populations are the smallest may control the distribution patterns of them in the following seasons. The ranges of water temperature and salinity in which *S. nageae* and *P. draco* occur in considerable number, being more than 10 individuals per 10 m³ of water are shown in Table 1.

2) Unusual occurrence of chaetognaths and oceanographical condition

In the Kuroshio both *S. nage* and *P. draco* occur simultaneously and in detail, *S. nage* dominates in the northern half of the current and *P. draco* prevails in the southern half of the current. This fact indicates that the coastal and the off-shore water are mixed through the Kuroshio.

Figs. 6-a~g show some unusual distributions of *S. nage* and *P. draco* and the currents determined with GEK. In May 1974 (Fig. 6-a) and May 1975 (Fig. 6-b), *S. nage* occurred in the off-shore area beyond the Kuroshio, being accompanied with a developed vortex to the south of the Kuroshio. *S. nage* might be thought to be carried by the Kuroshio and then by the vortex from the coastal area to the oceanic region. However, the mixing of water could not be confirmed from temperature and salinity.

In June 1976 (Fig. 6-c), May 1977 (Fig. 6-d), April 1978 (Fig. 6-e), June 1978 (Fig. 6-f) and April 1979 (Fig. 6-g), *P. draco* occurred in the coastal area, where a countercurrent of the Kuroshio which surrounds a cold water mass developed with the meandering of the Kuroshio is found. *P. draco* probably survived while they were carried by the Kuroshio and by its countercurrent to the coastal area. NAGASAWA and MARUMO (1978) described the life span of *S. nage* in the southern coast of Japan and obtained the values of about 3 to 7 months. These are thought to be an enough time to the above-mentioned processes.

It is concluded that the continuous observations of the individual numbers and the species composition of chaetognaths are very useful to monitor the change of the Kuroshio and the mixing of water in this area.

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本州南方における黒潮流路の変動とヤムシ類の分布との関係

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本州南方の定線において黒潮大蛇行期を含む1972~1980年に年4回測定したヤムシ類の種別組成から、沿岸種 *Sagitta nageae* と外洋種 *Pterosagitta draco* をとり上げてその分布と黒潮流軸の変化との関係を考察した。

S. nageae と *P. draco* の分布域は黒潮によって二分され、黒潮の蛇行期には大きく棲息域を変化させられている。

ヤムシ類は顕著な季節変動を示し、その分布パターンには水温・塩分の変動パターンとの間に約1季節の遅れがみられる。ヤムシ類の年間の分布パターンから、彼等が最も減少する冬季の海況はヤムシ類の高密度数を維持するのに不適であるが、その後の分布に影響を与えていると思われる。

S. nageae の外洋水域への、また *P. draco* の沿岸水域への出現は、同時に測定した GEK による流れのパターンによってよく説明することができ、両系水が黒潮に混入した後、大冷水塊に伴う逆流や黒潮南側に発達する渦流によって混合されてゆく過程を実証している。

Chlorophyll *a* and primary production in the Japan Sea

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Abstract: Measurements of chlorophyll *a* and phaeophytin were carried out in the winter and the summer of 1979 in the Japan Sea. The relation between water temperature and chlorophyll *a* concentration is examined. Primary productions in both seasons are estimated based on the chlorophyll *a* distributions. Primary production in winter is higher than that in summer.

1. Introduction

Chlorophyll *a* is the plant pigment for photosynthesis and one of the most important factors to estimate the primary production in the ocean.

The Japan Sea is characterized by the Tsushima Warm Current and the northern cold current, so-called the Riman Cold Current, and the Proper Water in the deep layer of the Japan Sea. Appearance of the two currents shows a large seasonal variation. The relation between marine environment and the primary production in the Japan Sea is a very interesting subject. In the Japan Sea, up to the present, detailed distribution of plant pigments has not been observed sufficiently (OHWADA, 1971), so that the seasonal and regional variations of primary production were not well known.

In this paper, the results of measurement of chlorophyll *a* and phaeophytin concentrations in the Japan Sea are reported first. Data are based on the cruises in the winter and the summer of 1979 aboard the R/V Seifu Maru of Maizuru Marine Observatory. Plant pigments were measured at all stations as shown in Fig. 1 together with other elements. The relation between plant pigment concentrations and the sea conditions is revealed.

Next, the primary production in the Japan Sea in winter and summer is estimated from the plant pigment data taking account of solar radiation and other factors.

2. Sample and method

Samplings were made both in the winter and the summer of 1979 at the same stations in the Japan Sea as shown in Fig. 1. Sea water samples were collected from the expected depths of 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, and 300 m with Nansen bottles. 250 ml of sea water collected at each depth was filtered through Whatman GF/C glassfiber filter. Plant pigments on the filters were preserved in dry and cold conditions for a few

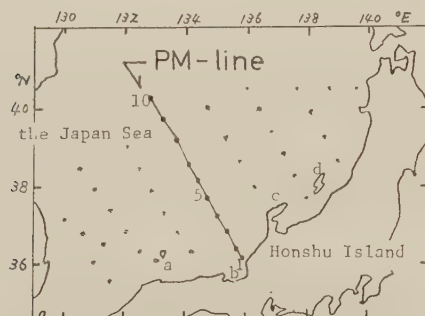


Fig. 1. Station location and PM line are shown in the map of the Japan Sea.
a: Oki Islands, b: Wakasa Bay, c: Noto Peninsula,
d: Sado Island.

days and extracted in 85% acetone. The concentrations of plant pigments were measured by fluorescence method according to YENTSCH and MENZEL (1963) and BABA et al. (1979).

3. Results and discussion

(1) Winter (3 February to 4 March 1979)

(a) Vertical distributions of water temperature, chlorophyll *a* and phaeophytin concen-

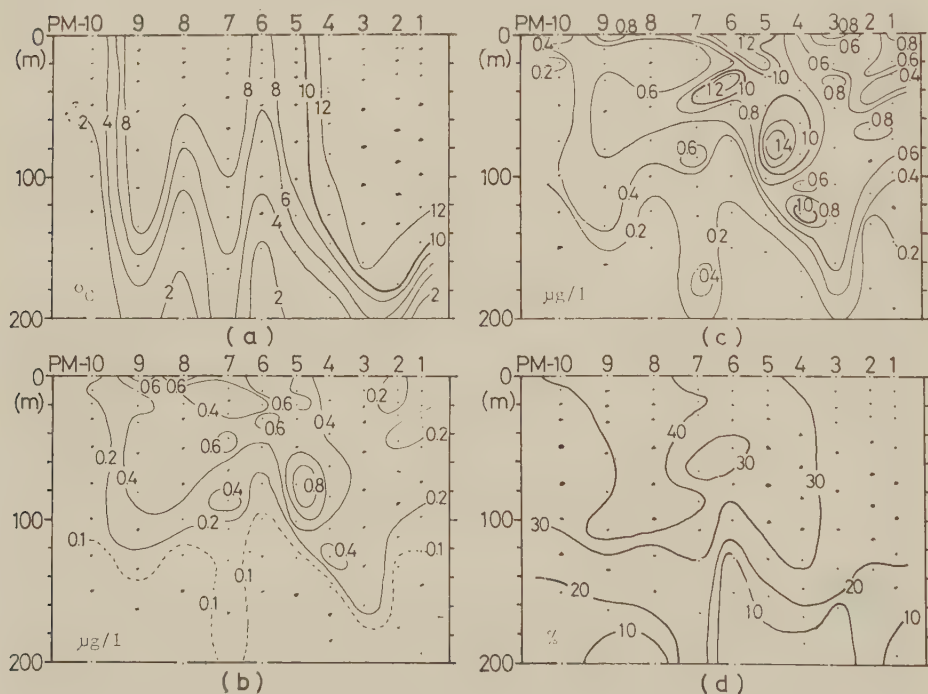


Fig. 2. Vertical distributions of water temperature (a), chlorophyll *a* (b), phaeophytin (c) and chlorophyll *a* ratio to the total pigments (d) along the PM line in winter.

trations along the PM line (refer Fig. 1) are shown in Fig. 2 as an example. As for the distribution of water temperature, there is warm water above 12°C in the upper layer of the coastal region, PM-1 to 4, and also warm water above 8°C from PM-7 to 9. There is, however, water colder than the surrounding water at PM-6 and cold water near 2°C at the sea surface of the northernmost station, PM-10, which may be originated from the northern part of the Japan Sea. Water temperature is constant in the upper layer from the surface to 100 m due to the vertical mixing.

In the vertical distributions of chlorophyll *a* and phaeophytin concentration, there is no maximum layer, though in other seasons it is sometimes found in the depth of 30 to 50 m. The isopleths of 0.2 µg/l of chlorophyll *a* and 0.4 µg/l of phaeophytin coincide with the thermocline. The amount of plant pigments in the surface layer is approximately constant by vertical mixing and is larger than that in deeper layer. The chlorophyll *a* ratio to the total pigments is around 20% in the warm water region, PM-1 to 4, and around 40% in the cold water region north of PM-8.

(b) Horizontal distributions of water temperature, chlorophyll *a* and phaeophytin concentrations and the ratio of chlorophyll *a* are shown in integrated mean from the sea surface to the depth of 100 m in Fig. 3. It is found in the water temperature distribution that the

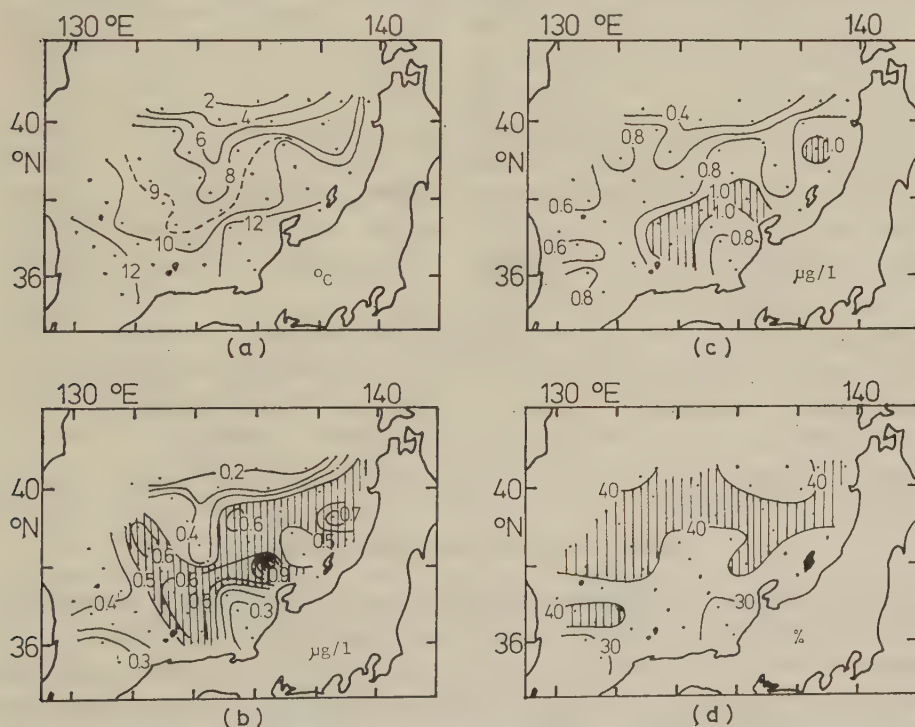


Fig. 3. Horizontal distributions of water temperature (a), chlorophyll *a* (b), phaeophytin (c) and chlorophyll *a* ratio (d) integrated mean from the sea surface to the depth of 100 m in winter.

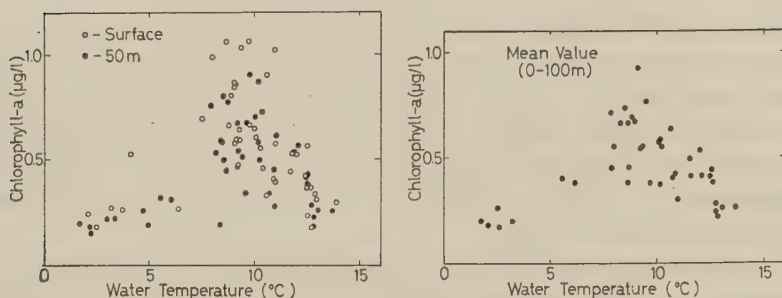


Fig. 4. Relations between chlorophyll *a* and water temperature at the sea surface and the depth of 50 m (a) and integrated mean from the sea surface to the depth of 100 m (b) in winter.

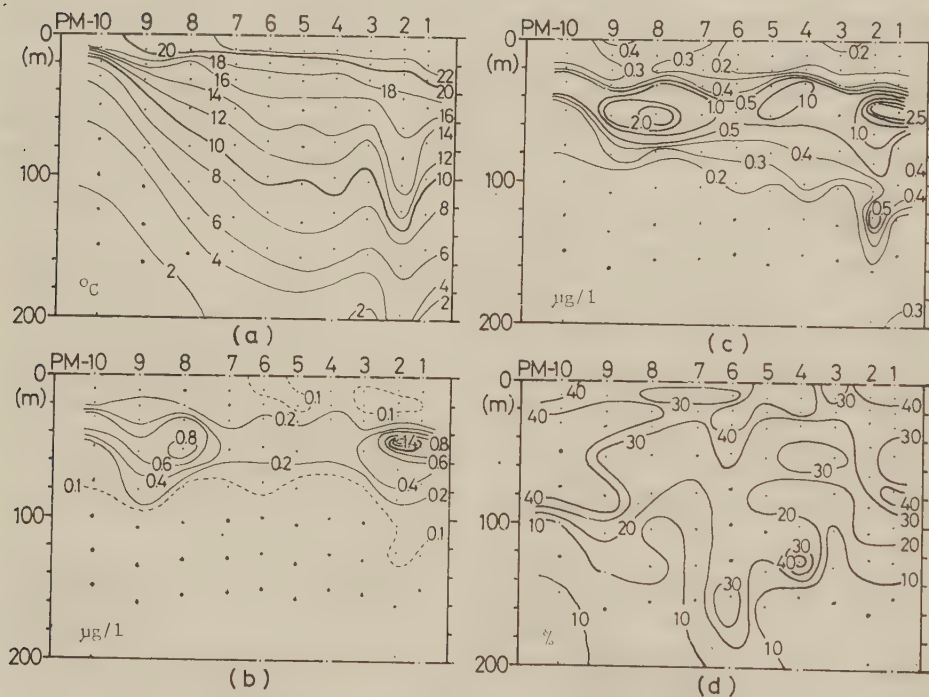


Fig. 5. The same as Fig. 2 but for summer.

warm water extends north of Wakasa Bay and northwest of Sado Island from the coast of Honshu Island and the cold water extends from far northwest of Noto Peninsula to the southward direction. The chlorophyll *a* concentration is low in the warm water region near coast and is also low in the offshore cold water region. In the intermediate region between the two water masses, it is higher than $0.5 \mu\text{g/l}$. Distribution of phaeophytin concentration is similar to that of chlorophyll *a* and the concentration in the cold water region is more than that of chlorophyll *a*.

The value of chlorophyll *a* ratio is low in the coast and the northern cold water regions and high in the intermediate region. There is an especially low value less than 30% in the east of Tsushima Straits and in the coast near Wakasa Bay.

(c) The relations between water temperature and chlorophyll *a* concentration are shown in Fig. 4 at the sea surface, at the depth of 50 m and the integrated mean from 0 m to 100 m. The patterns of the distribution are like a pyramid with the peak around 10°C. It means that the chlorophyll *a* concentration is low in both the warm and the cold water regions and high in the intermediate water temperature region. But several low values around 10°C suggest that chlorophyll *a* concentration does not depend on only water temperature. Salinity and dissolved oxygen content in sea water do not classify the distribution of it. The factors affecting it except temperature are unknown.

(2) Summer (4 to 31 July 1979)

(a) Vertical distributions along the PM line of water temperature, chlorophyll *a* and phaeophytin concentrations and the ratio of chlorophyll *a* are shown in Fig. 5. The distribution of temperature shows distinct stratification in contrast with in winter. Comparing with it, horizontal gradient of the water temperature at the sea surface along the PM line is very small. The isotherm of 10°C becomes gradually shallow offshoreward. The cold water occupies offshore region and the warm water occupies coastal region, PM-2.

In the vertical distribution of chlorophyll *a* concentration, there is a maximum layer around the depth of 50 m with especially high values at PM-1 and 2 in the coastal region and at PM-8 in the offshore region. The distribution of phaeophytin concentration is similar to that of chlorophyll *a*. Phaeophytin concentration is higher than 0.6 µg/l at the second thermocline located at the 125 m depth of PM-2. The chlorophyll *a* ratio is higher than 40% around the sea surface along the PM line and in the upper 100 m layer north of PM-8.

(b) Just as the winter case, horizontal distributions are shown in Fig. 6. As shown in Fig. 6 (a), the warm water extends west of Oki Islands, northwest of Wakasa Bay and west of Sado Island, while the cold water occupies north of Oki Islands and Noto Peninsula. Chlorophyll *a* concentration is mostly low in the warm water region except around Wakasa Bay as well as in winter. The value at 39°N 132°E is higher than 2.0 µg/l because of the exceptionally high value 12.45 µg/l at the depth of 30 m. The chlorophyll *a* concentration is less than 0.3 µg/l in the offshore cold water region. Phaeophytin concentration is low in the warm water region except in the coastal region around Wakasa Bay through Noto Peninsula. The chlorophyll *a* ratio is low in the coastal region and high in the offshore region. The chlorophyll *a* concentration is higher in winter than in summer as well as the phaeophytin concentration and the chlorophyll *a* ratio.

(c) The relation between water temperature and chlorophyll *a* concentration is shown in Fig. 7. Chlorophyll *a* concentration varies little at the sea surface, while at the depth of 50 m it is sometimes high around 12°C. As the chlorophyll *a* concentration is not always high around 12°C, it does not depend on only water temperature as well as in winter. The

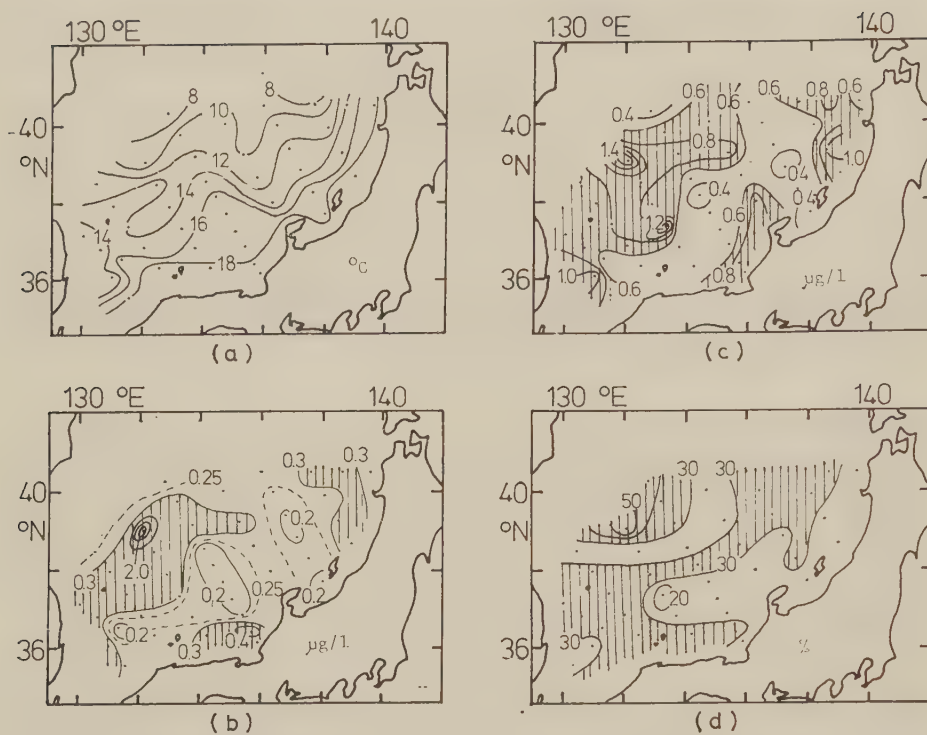


Fig. 6. The same as Fig. 3 but for summer.

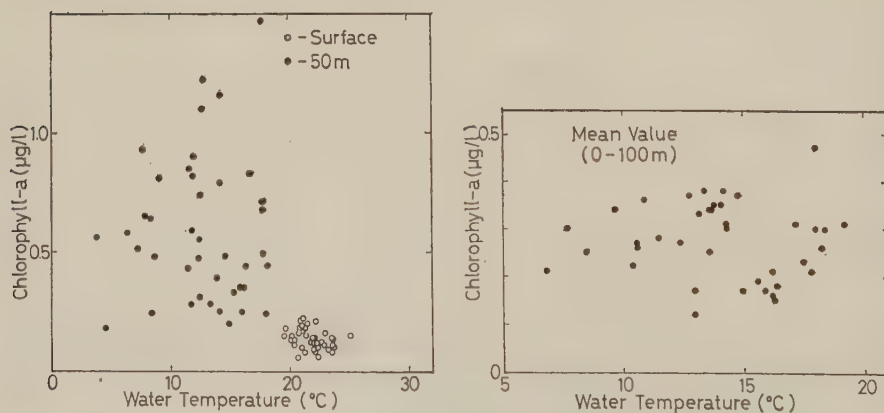


Fig. 7. The same as Fig. 4 but for summer.

areas of maximum concentration are in the boundary between the warm and the cold water in the distribution of chlorophyll *a* in winter. This fact is not clear in summer.

3. Primary production

Primary production can be measured by ^{14}C method directly. But it may be estimated from the chlorophyll *a* concentration as follows (SAIJO, 1973).

The intensity of radiation (I) at the depth of x is

$$I(x) = I(0) \exp\left(-\frac{2x}{D}\right)$$

where D is the mean value of transparency (about 20 m in both seasons in the Japan Sea).

The relative ratio of photosynthesis (R) is approximately represented as the following equation by RYTHER (1956).

$$R(x) = \frac{e}{2} I(x) \exp\left(-\frac{I(x)}{2}\right)$$

where the unit of I is 10^4 lux, that is, about $8.3 \text{ cal/cm}^2 \text{ hr}$. The value of $R(x)$ is zero at $I=0$ and increases with I for $0 < I \leq 2$, decreases for $I > 2$.

The primary production (P , $\text{gC/m}^2 \text{ day}$) can be calculated by the following equation.

$$P = P_{\max} T \int_0^\infty S(x) R(x) dx$$

where $S(x)$ is the vertical distribution of chlorophyll *a* concentration, $P_{\max}$ is maximum hourly photosynthesis value and T is the daily duration of sunshine.

Here, $P_{\max}$ is adopted $2.5 \text{ mg C/mg chl. } a \text{ hr}$. This value is the mean photosynthetic rate under the optical light condition for the samples in the mixed region of the Kuroshio and the Oyashio obtained by SAIJO and ICHIMURA (1960). The solar radiation and possible duration of sunshine in the Japan Sea are $170 \text{ cal/cm}^2 \text{ day}$ and 10 hours in winter and $330 \text{ cal/cm}^2 \text{ day}$ and 14 hours in summer, respectively (Maritime Meteorological Division of Maizuru Marine Observatory, 1972).

The daily production rate was calculated in both seasons as shown in Fig. 8. In winter the distribution of primary production rate is similar to that of chlorophyll *a* and low in the coast and the offshore cold water regions and high in the intermediate region. The mean value obtained in the Japan Sea is $0.21 \text{ gC/m}^2 \text{ day}$ in winter. In summer the distribution

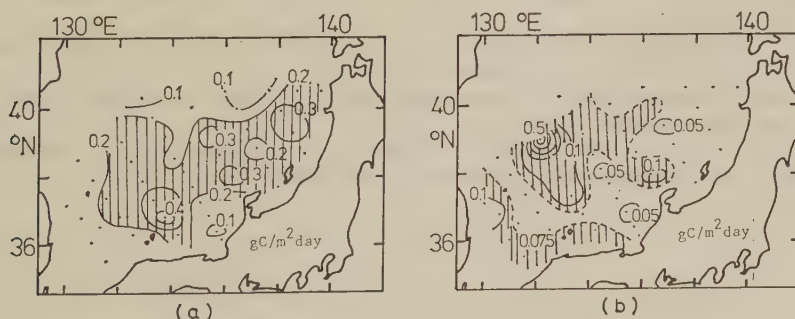


Fig. 8. Horizontal distribution of estimated primary production in winter (a) and in summer (b).

is a little different from that of chlorophyll *a* because the maximum layer of the chlorophyll *a* concentration varies within the range from the depth of 30 to 50 m. The concentration of chlorophyll *a* in the shallow depth contributes to the primary production with a strong light absorption. The mean photosynthesis value in summer is 0.08 g C/m² day less than half of that in winter, as a result of chlorophyll *a* concentration is low in the shallow depth in summer.

4. Conclusion

Amounts of plant pigments of phytoplankton in the Japan Sea are low in the regions of warm water and the offshore cold water and relatively high in the intermediate temperature region in both winter and summer seasons. It is estimated that the mean primary production rate in the Japan Sea are about 0.21 g C/m² day in winter and 0.08 g C/m² day in summer.

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日本海のクロロフィル *a* と基礎生産量

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1979年の冬季および夏季の日本海定期海洋観測において、海水中のクロロフィル *a* とフェオフィチンを広範囲に測定し、植物色素の分布を得た。水温とクロロフィル *a* の関係からクロロフィル *a* は暖水域、冷水域ともに少なく、両者の中間の海域で多いことが示された。さらに日射量などのデータを用いて基礎生産量の分布も推定した。結果は基礎生産量は夏季よりも冬季の方が多いことを示した。

NOTE

Characteristics of the tidal current deduced from the GEK data in the Eastern China Sea

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Abstract: Historical data set of sea surface current with GEK instruments were statistically treated to study the properties of tidal current on the continental shelf in the Eastern China Sea. In the semi-diurnal component of tidal current, it was revealed that the major axis of the tidal ellipse is perpendicular to the cotidal lines of M_2 tide and the current speed reaches its peak when the sea level at Nagasaki is in high water and low water.

1. Introduction

Continuous measurements of current over days are supposed to be essential for revealing the properties of tidal current of the ocean. However, the current observation for many hours are a very few in number because of difficulties of operation at sea. On the other hand, measurements of instantaneous current of sea surface can be easily carried out with GEK (Geomagnetic Electro Kinetograph) on board ships under way. In the Eastern China Sea as well as the other seas adjacent to Japan a large amount of GEK observations have been made by the Japan Meteorological Agency, the Maritime Safety Agency and the Fisheries Agency since 1950's.

Recently NAGATA et al. (1981) demonstrated that the measurements of sea surface current with GEK are effective not only in deep oceans but also in the shelf region of the Eastern China Sea, owing to the existence of thick conductive sedimentary layer in the upper part of sea floor. In the present study authors intend to examine properties of semi-diurnal tidal current on the continental shelf in the Eastern China Sea based on the GEK data obtained during many years.

2. Data processing

GEK data compiled at the Japanese Oceanographic Data Center from 1953 through 1970 were used for our statistical study. The work was focused on revealing features of tidal current in the sea west of Kyushu Island. In the other regions of the Eastern China Sea the number of data are too small to make analysis.

The following method was introduced to clarify properties of tidal current of semi-diurnal component that is dominant in the Eastern China Sea. The period between two consecutive high tides at Nagasaki where semi-diurnal variation is extremely recognized

was divided into 12 equal time segments. In a set of the 12 time segments, concurrent GEK data were put according to the observation times. For each of time segments, current speeds in it were averaged. From these 12 averaged values, amplitude and phase of semi-diurnal tidal current were estimated by the least square method. The computation was made for the data obtained in each 30 minutes latitude by 30 minutes longitude square.

In order to show the validity of our above-mentioned data processing, we examined continuous records obtained by a moored current meter on the shelf. The data at the depth of 50 m below sea level from April 27 to 29, 1969 at $32^{\circ}45'N$, $128^{\circ}21'E$ was analysed to estimate amplitude and phase of semi-diurnal variation by the least square method. Fig. 1 gives the tidal ellipse deduced from GEK data set in the square including the mooring site (dashed line) and that from the continuous records (solid line). In the figure times of high and low waters at Nagasaki are marked 0 and 6, respectively, and arrows indicate the direction of rotary motion. From the figure it is seen that the difference in phases of two ellipses

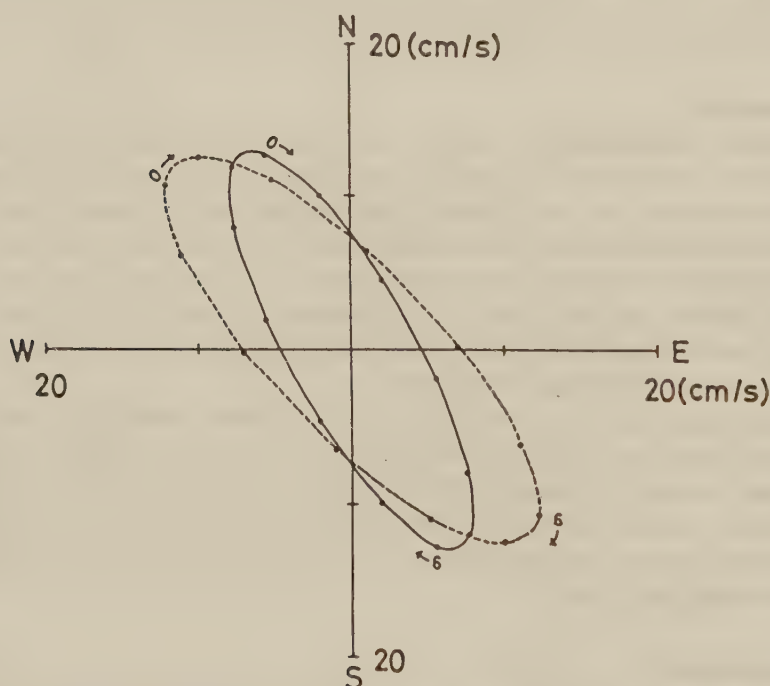


Fig. 1. Comparison between the tidal ellipses deduced from the GEK data and from direct current measurements. The solid line indicates the ellipse deduced from the data obtained from moored current meter ($32^{\circ}45'N$, $128^{\circ}21'E$), and the dashed line that derived statistically from the GEK data in the square ($32^{\circ}30' - 33^{\circ}N$, $128^{\circ} - 128^{\circ}30'E$) including the site. The times of high water and low water at Nagasaki are marked 0 and 6, respectively. Arrows indicate the direction of rotation of current vectors. The period of measurements, depth of water and level of the moored current meter are Apr. 27-29 in 1969, 237 m and 50 m, respectively.

is about one hour and the difference in amplitudes is less than 5 cm/s, which is nearly equal to the accuracy of current measurements by both methods.

3. Results

Tidal ellipses of semi-diurnal current obtained with our procedure were illustrated in Fig. 2. The numerals 0 and 6, and arrows in the figure are the same as in Fig. 1. The numerals in the bottom of each square show the numbers of GEK data treated in the present analysis. From the figure characteristics of semi-diurnal tidal current on the continental shelf west of Kyushu Island are revealed as follows.

- (1) The major axis of tidal ellipse is perpendicular to cotidal lines for M_2 (cf. Fig. 3), as well as to bathymetric lines.
- (2) The tidal current is expect to peak when the sea level at Nagasaki is in high and low waters.
- (3) The peak speed of current tends to become larger as the water depth decreases.

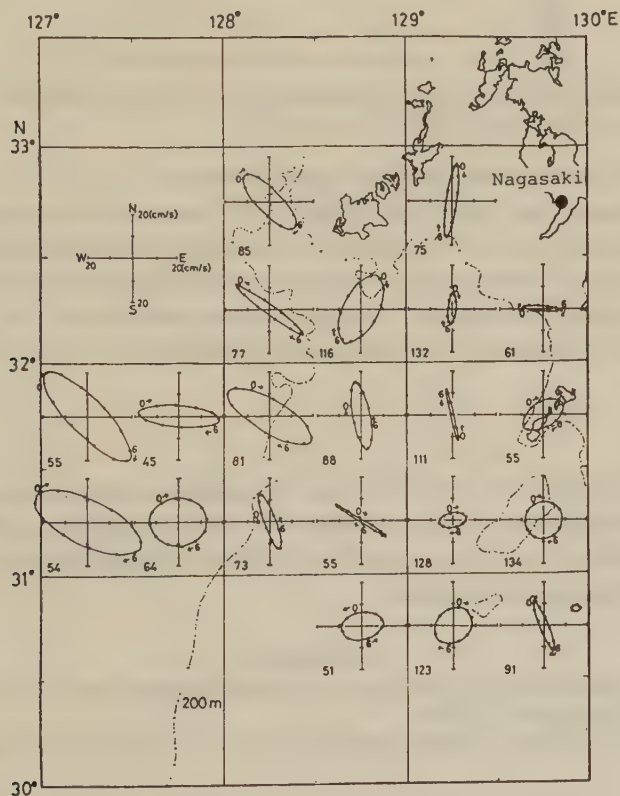


Fig. 2. Tidal ellipses of the semi-diurnal current component statistically deduced from GEK data. The numerals 0 and 6, and arrows are the same as Fig. 1. The numeral attached in each square indicates the number of analysed data.

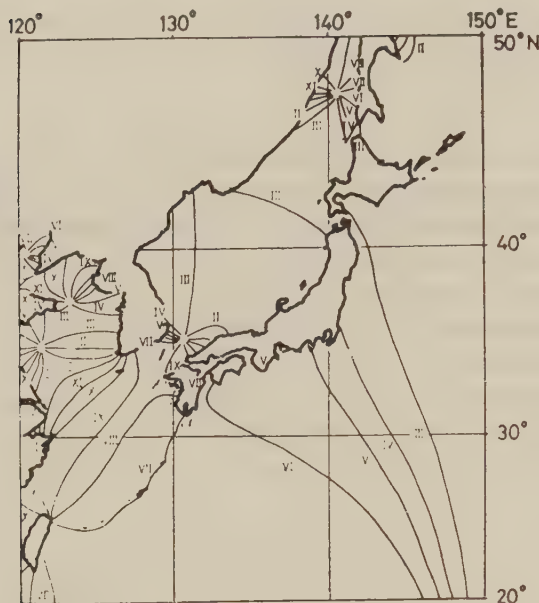


Fig. 3. Cotidal lines for M_2 tide in the seas adjacent to Japan (in lunar hours relative to moon's transit over 135°E). (OGURA, 1933)

(4) Rotary motion associated with tidal current is clockwise.

In the deep water region and in the shallow region close to Kyushu Island, the direction of major axes of tidal ellipses are scattered from a square to another square and peak speed is relatively small. Unfortunately, information on electrical conductivity of the ocean floor in those regions is too limited to evaluate the effectiveness of the GEK measurements. Therefore, detailed discussion on the properties of tidal current for the waters remains in future work.

4. Summary

We demonstrated that the GEK observations sporadically made are useful to reveal characteristics of tidal current on the continental shelf. This provides us a certain possibility of predicting the tidal current on the shelf of the Eastern China Sea when once the GEK observations are adequately occupied.

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GEK データから推定された東シナ海の潮流の特性

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GEK データを使って東シナ海大陸棚域の半日周潮流の性質について調べた。その結果、潮流楕円の長軸方向は M_2 分潮の等潮時線に直交しており、潮流の流速は長崎における満干潮時に最大とすることがわかった。

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